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FINAL AREAS A AND C SOURCE TREATMENT OPTIMIZATION PLAN NAWC WARMINSTER PA
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BATTELLE

FINAL

Areas A and C Source Treatment Optimization Plan for the Former NAWC Warminster, Pennsylvania

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ABBREVIATIONS AND ACRONYMS

bgs	below ground surface
CCl_4	carbon tetrachloride
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
COC	contaminant of concern
CSM	conceptual site model
DCE	dichloroethene
DNAPL	dense, non-aqueous phase liquid
DQO	data quality objective
gpm	gallons per minute
GWETS	groundwater extraction and treatment system
ISCO	in situ chemical oxidation
LGAC	liquid-phase granular activated carbon
LTM	long-term monitoring
MCL	maximum contaminant level
NAWC	Naval Air Warfare Center
NPV	net present value
OU	Operable Unit
PCE	tetrachloroethene
PDB	passive diffusion bag
PID	photoionization detector
QAPP	Quality Assurance Project Plan
ROD	Record of Decision
RSL	regional screening level
SOD	soil oxidant demand
TCE	trichloroethene
TEG	Technical Evaluation Group
TI	technical impracticability
U.S. EPA	U.S. Environmental Protection Agency
VOC	volatile organic compound

Section 1.0: INTRODUCTION

Battelle has prepared this source treatment optimization plan for Area A and Area C at the former Naval Air Warfare Center (NAWC) in Warminster, Pennsylvania. The activities proposed within this plan are based on recommendations and information from prior optimization evaluations and investigations, and are focused on planning and implementing aggressive source treatment at Area A, and refining plume architecture at Area C.

1.1 Background

The former NAWC Warminster is situated in a populated suburban area surrounded by private homes, various commercial and industrial activities, and a golf course. Commissioned in 1944, the facility's main function was research, development, testing, and evaluation for naval aircraft systems. NAWC Warminster also conducted studies in anti-submarine warfare systems and software development. Historically, wastes were generated during aircraft maintenance and repair, pest control, fire-fighting training, machine and plating-shop operations, spray painting, and various materials research and testing activities in laboratories. These wastes, including paints, solvents, sludges from industrial wastewater treatment, and waste oils, were disposed of in several pits, trenches, and landfills throughout the facility property.

NAWC Warminster was listed on the Superfund National Priorities List in 1989. This list includes six sites where uncontrolled hazardous substance releases present the most significant potential threats to human health and the environment. These sites have been grouped within the following areas on NAWC property (Figure 1): Area A (Sites 1, 2, and 3); Area C (Sites 4 and 8); and Area D (Site 9). As a result of elevated chlorinated volatile organic compound (VOC) concentrations observed in groundwater, a groundwater extraction treatment system (GWETS) was installed at Area A to treat groundwater extracted from Areas A, C, and D. Pumping from Area D was discontinued in 2010 after the remedial goals (i.e., maximum contaminant levels [MCLs]) were achieved at the Area D extraction wells. Pumping from Areas A and C is currently ongoing. A technical impracticability (TI) waiver zone has been established within Area A (near Site 1) due to high concentrations of trichloroethene (TCE) and potentially carbon tetrachloride (CCl_4) and tetrachloroethene (PCE), which are indicative of the presence of dense non-aqueous phase liquid (DNAPL). A long-term monitoring (LTM) program is in place at Areas A, C, and D to monitor the presence of dissolved VOCs in groundwater.

1.2 Objective

The objective of this source treatment optimization plan is to prepare a consolidated plan for implementation of optimization efforts for aggressive source treatment at Area A, and for refinement of plume architecture in Area C. The plan will provide a framework for efforts over the next two to three years to identify tasks for data collection and design of these optimization efforts. This plan is based on previous optimization evaluations and site investigation activities, including the *Remedial Action Evaluation Report for Operable Units 1A, 3, and 4 Groundwater Treatment System at NAWC Warminster, Pennsylvania* (Battelle, 2011), the *Area C Source Assessment Report, Former Naval Air Warfare Center Warminster, Warminster, Pennsylvania* (Tetra Tech NUS, 2007), and the *Hydrogeologic Conceptual Site Model Update* (Tetra Tech, 2009).

This plan will be followed by work plans specific for the activities proposed at each area, including extraction well profiling at Areas A and C, and soil and rock core collection in Area A for in situ chemical oxidation (ISCO) bench testing. The remainder of this plan presents a summary of previous evaluations to serve as a foundation for future optimization efforts, and the overall approach and schedule of proposed source treatment optimization activities at Areas A and C.

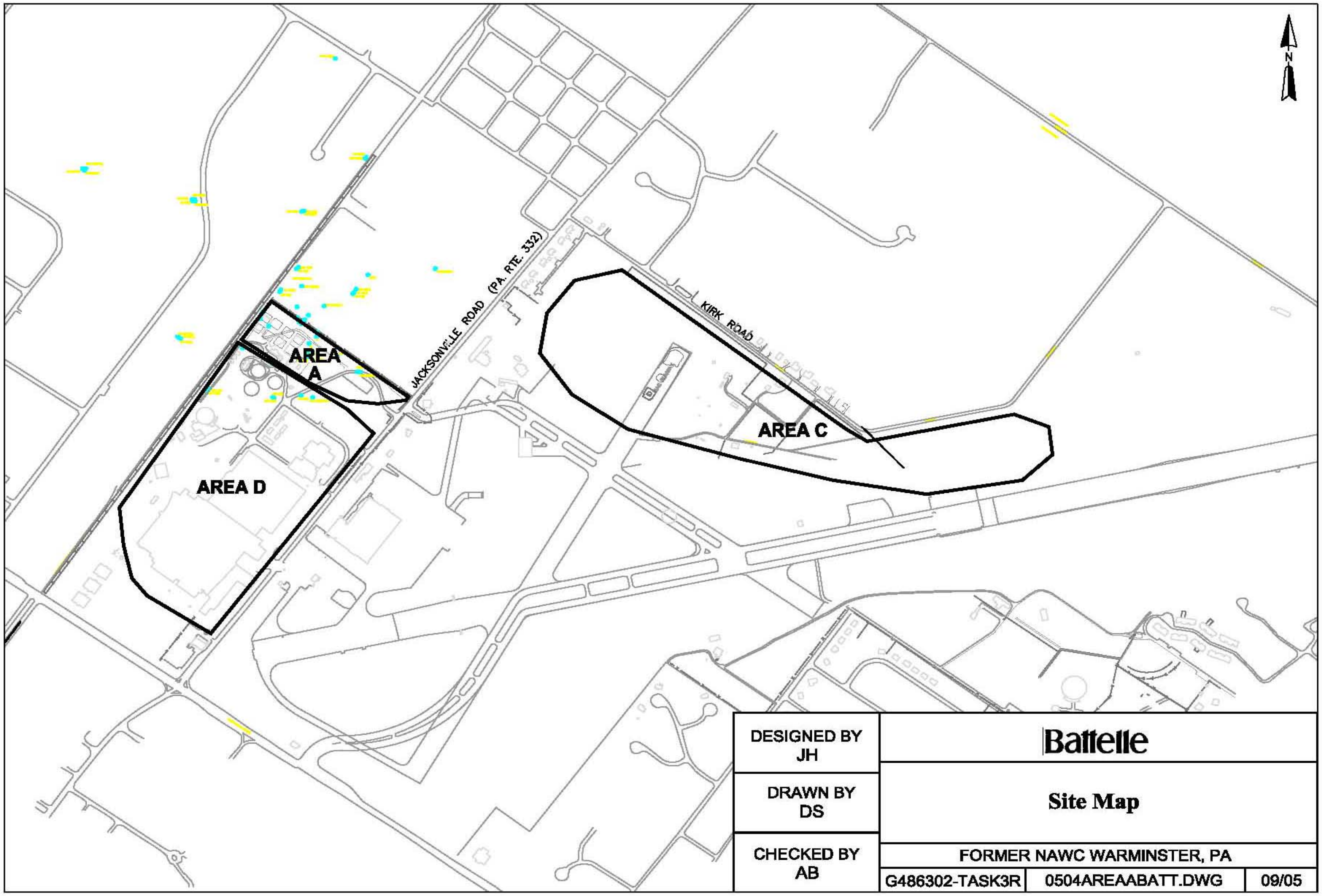


Figure 1. NAWC Warminster Site Map

Section 2.0: SITE DESCRIPTION AND CURRENT CONDITIONS

The following subsections describe the conceptual site model (CSM) and current status of the remedial activities at Area A and Area C.

2.1 Area A

Area A is comprised of three sites, Sites 1, 2, and 3, and lies within the northwest corner of the former Base, west of Jacksonville Road (Figure 2). Site 1 was operated as a burn pit, Site 2 consisted of two disposal trenches that received industrial wastewater sludges from the surface impoundments, and Site 3 was also reportedly used as a burn pit for solvents, paints, roofing materials, and other unspecified chemicals. Eight unlined lagoons used for storage of wastewater treatment plant sludges were formerly operated in the northern corner of Area A.

Within Area A, the presence of TCE in the form of DNAPL has been inferred based on the concentrations detected in groundwater and confirmed through dye testing performed during extraction well drilling, yield testing, and sampling activities. Samples with positive dye test results included EW-A6, EW-A7, and EW-A10, and these results also coincided with laboratory analyses showing TCE concentrations of 100 mg/L or greater during the 1999 sampling activities. A TI evaluation performed in 2000 estimated that approximately 75 to 374 gallons of TCE were potentially present as DNPAL in Area A. The evaluation concluded that no currently available remedial technology can reliably and safely achieve removal of the DNAPL from the bedrock aquifer, and that complete dissolution of the DNAPL and follow-on attainment of cleanup levels will likely take well over 100 years. As a result of the evaluation, an 85-ft diameter TI zone was established in Area A focused around extraction wells EW-A6, EW-A7, EW-A9, and EW-A10 (Figure 2).

Pump and treat was selected as the final groundwater remedy in Area A, and a GWETS was installed and began operation in 1999. The cleanup goals identified in the Record of Decision (ROD) are MCLs throughout Area A, with the exception of the TI waiver zone where achieving these goals was determined to be technically impracticable. Details regarding the GWETS are discussed in Section 2.1.2. A preliminary cost analysis presented in the *Remedial Action Evaluation Report (*Battelle, 2011) indicates that source area treatment can effectively reduce the overall life-cycle cost and timeframe for achieving remediation goals at Area A compared to the GWETS remedy currently operating. The target area for this treatment was identified as the area with TCE concentrations remaining above 5.0 mg/L, which encompasses the TI waiver zone and likely residual DNAPL in the vicinity of extraction wells EW-A6, -A7, -A9, and -A10 (Battelle, 2011). The following CSM discussion focuses on this target treatment area, and will serve as a basis for developing a strategy for obtaining the additional information necessary to support further evaluation and design of a source area treatment remedy.

2.1.1 Current CSM. The geology of Area A consists of alternating coarse- and fine-grained sedimentary bedrock units of the Stockton Formation underlying a thin veneer of clayey residual soils. The soils consist primarily of silt and clay, with minor amounts of sand and rock fragments. Typically, the soils transition into weathered bedrock at depths of roughly 8 to 10 ft below ground surface (bgs), and to competent bedrock at an average depth of 15 ft bgs. The transition from soils to weathered bedrock to competent bedrock occurs gradually and varies somewhat in depth across Area A. Soils in the TI waiver zone tend to transition at a shallower depth. According to information collected from several soil borings and test pits (see Attachment A), TI waiver zone soils tend to fade to weathered bedrock at a depth of 6 to 9 ft and competent bedrock below 9 ft (Table 1) (Tetra Tech, 2000; Halliburton NUS, 1993).

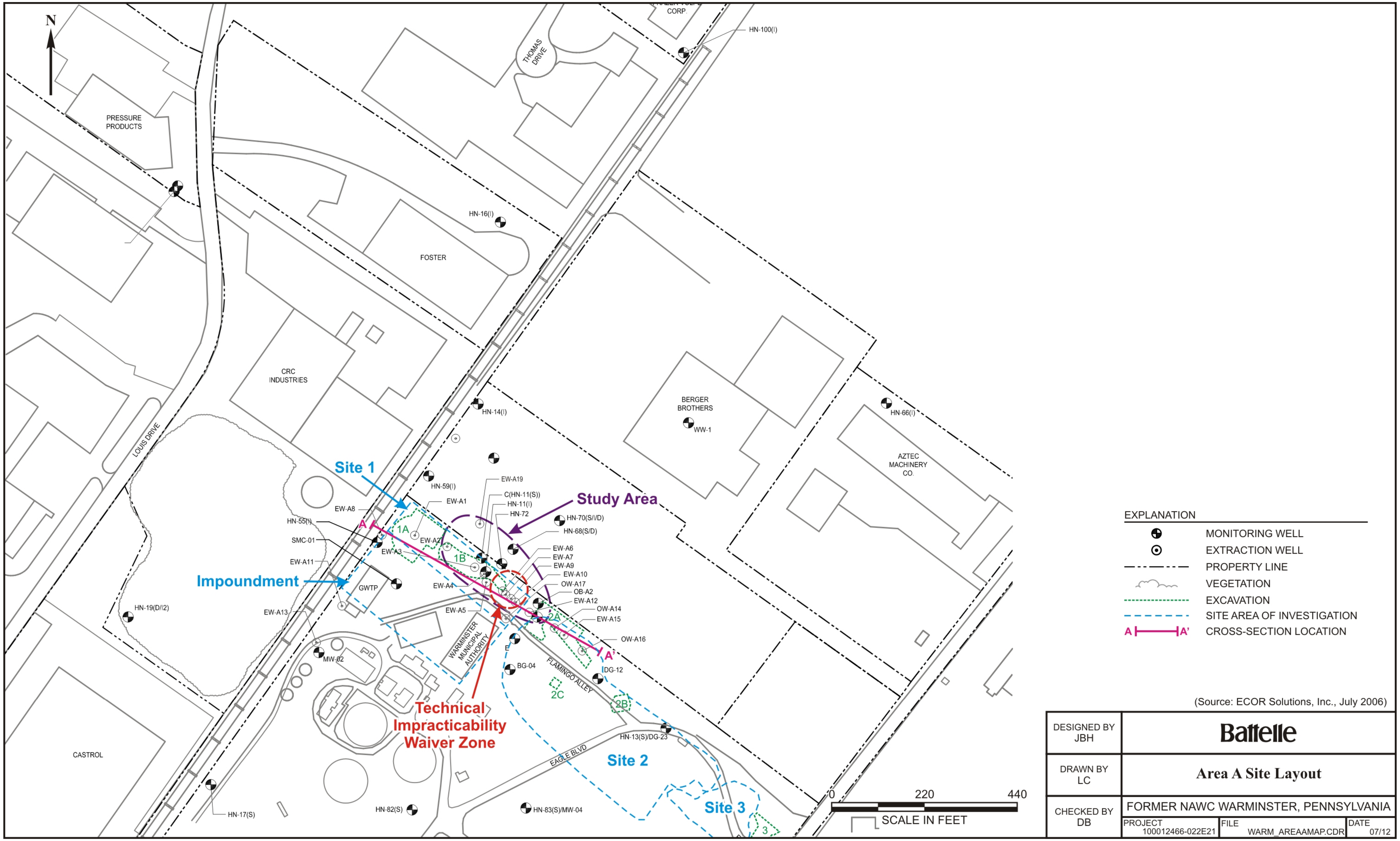


Figure 2. Area A Site Layout

Table 1. Results of Soil Borings and Test Pits Described by Tetra Tech (2000) and Halliburton NUS (1993)

<table>
<tr><th>Depth</th><th>SI-11</th><th>SI-13</th><th>SI-10</th><th>SI-6</th><th>SI-12</th><th>SB-01-04</th><th>SB-01-05</th><th>SB-01-06</th><th>SB-01-07</th><th>SB-01-23</th><th>SB-01-25</th><th>SB-01-66</th><th>SB-01-67</th><th>SB-01-68</th><th>SB-01-70</th><th>SB-01-71</th><th>TP05-01-05</th><th>TP05-01-06</th><th>TP05-01-07</th></tr>
<tr><td>0</td><td rowspan="4">Brown organic Silt</td><td rowspan="3">Brown organic Silt w. glass; cinders</td><td rowspan="3">Medium-grained organic silt</td><td rowspan="8">Dark brown silt with gravel</td><td rowspan="4">Brown organic silt w. cinders</td><td rowspan="5">Silty clay; sticky</td><td rowspan="5">Silty clay</td><td rowspan="2">Silty clay</td><td rowspan="11">Silty clay</td><td rowspan="3">Clayey silt</td><td rowspan="3">Sandy clayey silt</td><td rowspan="6">Clayey silt</td><td rowspan="2">Silty clay</td><td rowspan="7">Clayey silt</td><td rowspan="3">Clayey silt</td><td rowspan="4">Silty clay</td><td rowspan="3">Silty clay</td><td rowspan="7">Silty clay</td><td rowspan="2">Gravel</td></tr>
<tr><td>0.5</td></tr>
<tr><td>1.5</td><td rowspan="3">Clayey silt</td><td rowspan="3">Clayey silt with siltstone frags</td><td>Sandy silt</td></tr>
<tr><td>2.5</td><td rowspan="9">Red medium-grained silt</td><td rowspan="2">Orange clayey silt</td><td rowspan="2">Clay</td><td>Clayey silt</td><td rowspan="7">Silt w. silt- and sandstone fragments</td><td rowspan="2">Weathered siltstone w. silty clay</td><td rowspan="4">Sandy clayey silt</td></tr>
<tr><td>3.5</td><td rowspan="3">Orange brown clay</td><td rowspan="2">Brown clay w. cinders</td><td>Clay</td><td rowspan="2">Clayey silt w. sandstone fragments</td></tr>
<tr><td>4.5</td><td rowspan="5">Red, fine-grained silt with gravel</td><td rowspan="2">Silty clay; trace sand</td><td rowspan="2">Clayey silt</td><td rowspan="2">Weathered siltstone</td><td rowspan="2">Clayey silt</td><td>Silty sand</td><td rowspan="5">Weathered bedrock</td><td rowspan="2">Weathered shale/siltstone</td></tr>
<tr><td>5.5</td><td rowspan="5">Red med. grain silt</td><td rowspan="2">Clayey silt</td><td rowspan="3">Weathered siltstone</td><td rowspan="4">Weathered bedrock</td></tr>
<tr><td>6.5</td><td rowspan="5">Red medium grained Silt</td><td rowspan="5">Siltstone bedrock</td><td rowspan="5">Weathered siltstone bedrock</td><td rowspan="5">Siltstone bedrock</td><td rowspan="3">Silty clay</td><td rowspan="2">Weathered bedrock</td><td rowspan="5"></td><td>Siltstone</td><td rowspan="2">Silty clay</td></tr>
<tr><td>7.5</td><td rowspan="4">Bedrock</td><td rowspan="2">Clayey silt w weathered siltstone</td><td rowspan="4"></td></tr>
<tr><td>8.5</td><td rowspan="3"></td><td rowspan="3"></td><td>Bedrock</td></tr>
<tr><td>9.5</td><td rowspan="2">Bedrock</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>10.5</td><td>Shale chips</td><td>Bedrock</td></tr>
</table>

Groundwater in the vicinity of Area A occurs primarily within the underlying bedrock units. Groundwater is encountered in discrete fractures within the rock matrix, and interconnected networks of fractures within the bedrock serve as the primary groundwater migration pathways. Within the bedrock, the sandstone units function as the primary water-transmitting units, and the fine-grained mudstone units act as semi-confining layers to groundwater flow. Both sandstones and mudstones are fractured to varying degrees; however, fractures in the sandstones tend to have higher yields and, as a result, the sandstone units act as preferential zones of groundwater flow.

Groundwater at Area A has been divided into hydrogeologic units A, B, and C, representing sequential units with depth. Each hydrogeologic unit consists of one or more laterally extensive sandstone beds and adjacent mudstone units, which, based on hydrogeologic and water quality data, form an interconnected, discrete groundwater flow system. Figure 3 illustrates the presence of hydrogeologic units A, B, and C along an east-west cross section through the source area at Area A.

Hydrogeologic unit B is the middle water-bearing unit and is the hydrogeologic unit of most importance in terms of groundwater contaminant occurrence and migration from Area A, and will serve as the target zone for source treatment in Area A. This hydrogeologic unit is comprised of the sandstone unit found at shallow depths and is generally found at depths of 15 to 100 ft bgs in Areas A. Within Area A and in the near-downgradient area, the sandstone bed is locally split by a thin mudstone unit that pinches out further to the north and east. To the north-northwest of Area A, hydrogeologic unit B is found at increasing depths, following the overall dip of the geologic units. Hydrogeologic unit B is the hydrogeologic unit within which the highest levels of contamination have been discovered within Area A, and consequently the source area extraction wells are screened within this unit (see Figure 3). A potentiometric surface map created from groundwater elevations collected during May 2012 is presented in Figure 4. Groundwater flow within this unit is generally toward the north in Area A and has been significantly affected by operation of the groundwater extraction system. Operation of the groundwater extraction system has lowered the current water table to a depth below the shallow water-bearing fracture zone within the source area (Figure 3).

Fourteen of the Area A extraction wells (EW-A01 through EW-A14) along with four observation wells (OW-A2, OW-A14, OW-A16 and OW-A17) were characterized in 1999 during the well installation activities (Foster-Wheeler Environmental Corp., 1999). Characterization of the wells included drawdown, yield, and recovery tests, water quality testing, and sustainable yield and capture zone analysis. During the yield test it was observed that fracture zones contributed to increased airlift yield. These depths were noted and reported as fracture yield zones. Although fractures were found at many areas between the depths of 13 to 86 ft bgs, the majority of the fractures were found in clusters between the depths of 22 to 30 ft bgs and 60 to 72 ft bgs. The fractures were encountered both at lithologic contacts (bedding plane fractures) and within lithologic units (cross bedding fractures). Table 2 shows the depths at which appreciable water-bearing fractures were found at each of the wells characterized during this event. It should be noted that these fracture zones may not by hydraulically active, and that the presence of water bearing zones should be confirmed via geophysical logs and/or well profiling. Figure 3 shows the fractured yield zones in select wells completed in the vicinity of the source area at Area A, as identified during these previous investigation activities.

As part of this work, a study area that included wells surrounding the proposed treatment area was defined. This study area, which is outlined in Figure 2, is demarcated (and includes) the following wells: EW-A2, EW-A19, HN-68D, OB-A2, EW-A12, and OW-A17. A full list of the wells included in the study area along with select chemical concentration data from the most recent sampling event (May 2012) is available in Table 3.

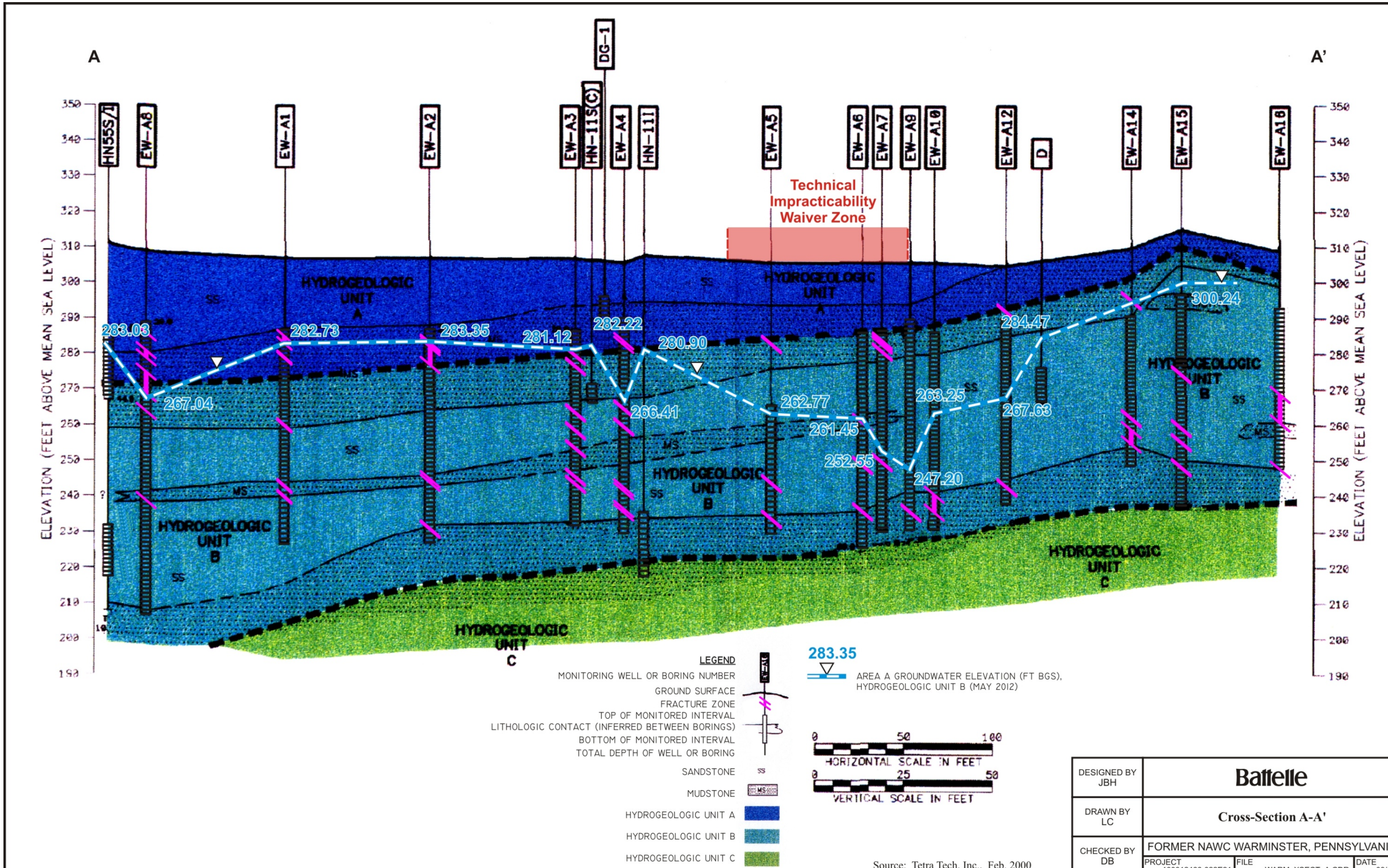


Figure 3. Geologic Cross Section from West to East across the Northern Edge of Area A (Tetra Tech NUS, Inc., 2000)

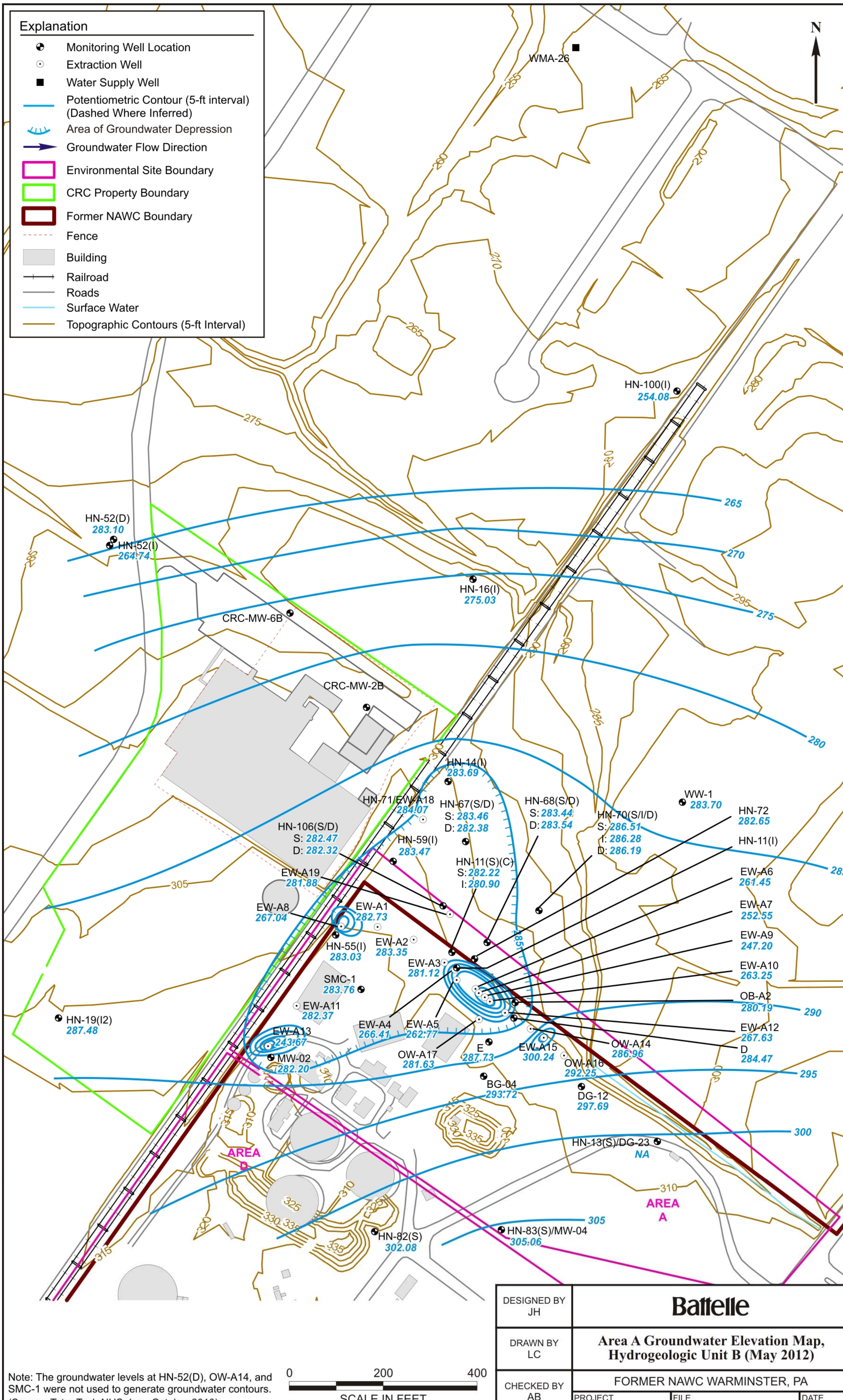


Figure 4. May 2012 Area A Groundwater Elevation Map for Hydrogeologic Unit B

Table 2. Fracture Zones in Area A

Well	Fracture Zones (ft bgs)		
	12-30 ft bgs	30-60 ft bgs	60-86 ft bgs
EW-A1	22, 24, 28	47	64, 67
EW-A2	24, 25-30	None	62, 63, 76
EW-A3	27, 30	43, 48, 53	61, 63
EW-A4	22-23	41,46	63-64, 69-70
EW-A5	23	None	62, 72
EW-A6	None	45, 57	70
EW-A7	22, 23, 25	56	None
EW-A8	23, 28-30	34-40, 45	70
EW-A9	None	None	70
EW-A10	None	None	65-67
EW-A11	28-30	None	84
EW-A12	13	None	62
EW-A13	None	36-38	69, 86
EW-A15	None	56	60-67
OW-A2	None	50-52	60-62, 70
OW-A14	15	48, 54-55	None
OW-A16	None	40-48	61
OW-A17	None	48, 58-59	68-69, 71.5

(Foster-Wheeler Environmental Corp, 1999)

Historically, the majority of contamination has been present in hydrogeologic unit B; accordingly, every well in the defined study area was screened within this unit. May 2012 TCE and CCl4 concentrations are presented in Figure 5. The most prevalent contaminant in the study area is TCE, and TCE is present at every well in the study area. TCE concentrations range from 0.17 (estimated) to 18,000 µg/L with an average of 1,850 µg/L and a median of 83.5 µg/L. The median and mean are considerably different because four of the wells in the study area exceed 1,000 µg/L (EW-A6, EW-A7, EW-A9, and HN11I), thus skewing the mean. TCE was detected at concentrations exceeding its MCL (5 µg/L) at 12 of the 16 wells in the study area.

Concentrations of TCE in GWETS extraction wells in the study area have been decreasing since the system was first installed in 1999 (see Figure 6). Many of the extraction wells in the study area had initial concentrations of TCE exceeding 10,000 µg/L (all except EW-A2, EW-A3, EW-A12, and EW-A19); reported TCE concentrations at two of the extraction wells in the study area (EW-A6 and EW-A7) initially exceeded 100,000 µg/L.

In addition to TCE, concentrations of PCE and CCl_4 exceeded their MCLs (both are 5 µg/L) at a total of three and seven wells, respectively, screened in hydrogeologic unit B. The average concentration of PCE in the study area is roughly 10.8 µg/L, with a maximum concentration of 62 µg/L (EW-A6). All of the wells where the concentration of PCE exceeded the U.S. Environmental Protection Agency (U.S. EPA) MCL were within the vicinity of the row of Area A extraction wells. The average concentration of CCl_4 in the study area is 20 µg/L, with a maximum of 140 µg/L (estimated) at EW-A6. All of the wells where the concentration of CCl_4 exceeded the U.S. EPA MCL are within the vicinity of the row of Area A extraction wells.

Table 3. Selected May 2012 Chemical Concentrations in Study Area Wells

Well ID	CCl_4	Chloroform	1,1-DCE	*cis*-1,2-DCE	PCE	TCE
MCL (µg/L)	*5*	*80*[(1)]	*7*	*70*	*5*	*5*
EW-A2	0.20 U	0.20 U	0.30 U	0.30 U	0.20 U	0.17 J
EW-A3	1.5	0.33 J	0.97 J	0.29 J	1.8	**37 J**
EW-A3-DUP	1.6	0.31 J	1.2	0.25 J	2.2	**29**
EW-A4	**9.6 J**	2.5 U	3.8 U	3.8 U	13	**240**
EW-A5	**36 J**	7.8 J	12 U	12 U	**62**	**750**
EW-A6	**140 J**	40 U	60 U	60 U	40 U	**4,100**
EW-A7	**46 J**	40 U	60 U	60 U	40 U	**3,100**
EW-A9	**58 J**	24 J	38 U	38 U	**33 J**	**2,900**
EW-A10	**12**	2.8 J	3.0 U	3.0 U	5.3 J	**200**
EW-A12	4.4 J	0.91 J	1.5 U	1.5 U	3.9 J	**84**
EW-A19	0.60 U	0.60 U	0.90 U	0.77 J	1.0 J	**84**
HN-11I	200 U	200 U	300 U	300 U	200 U	**18,000**
C (HN-11S)	0.20 U	0.20 U	0.30 U	5.1	0.22 J	**15**
HN-68D	0.93 J	0.20 U	0.30 U	0.30 U	0.87 J	0.77 J
HN-72	**5.0**	1.9 J	1.5 U	1.5 U	2.8 J	**83**
OB-A2	0.20 U	0.20 U	0.30 U	0.30 U	0.53 J	0.65 J
OW-A17	3.6	0.66 J	0.30 U	0.48 J	**6.2**	3.1
Minimum[(2)]	0.93 J	0.31 J	0.97 J	0.25 J	0.53	0.17 J
Maximum	140 J	24 J	1.2	5.1	62	18,000
Mean[(3)]	20.0	2.90	0.63	1.02	10.8	1,740
Median[(3)]	4.7	0.32	ND	ND	3.35	84

ND – non-detect
J – estimated value
Bold indicates concentration exceeds regulatory level.
(1) Target cleanup level established in the Sampling and Analysis Plan (H&S Environmental, Inc., 2011).
(2) Minimum detected concentration.
(3) Non-detected values were treated as values equal to one-half of the detection limit. Non-detected values at HN-11I, EW-A5, EW-A6, EW-A7 and EW-A9 were not used for the analytes chloroform, 1,1-DCE, and *cis*-1,2-DCE because the detection limits were higher than any detected value and would have unnecessarily skewed the data. The same was done for non-detected values of PCE and CCl_4 at well HN-11I only.

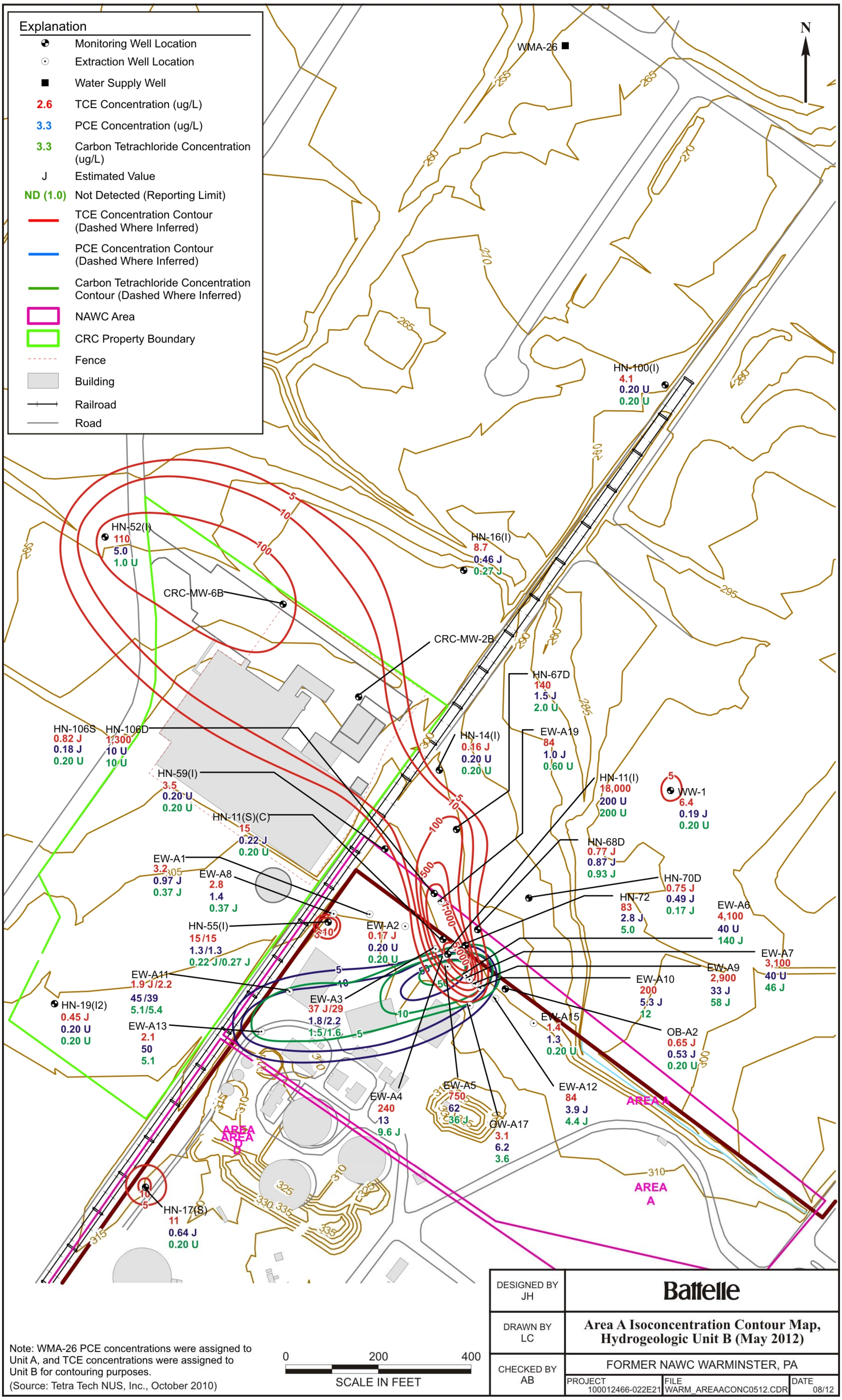
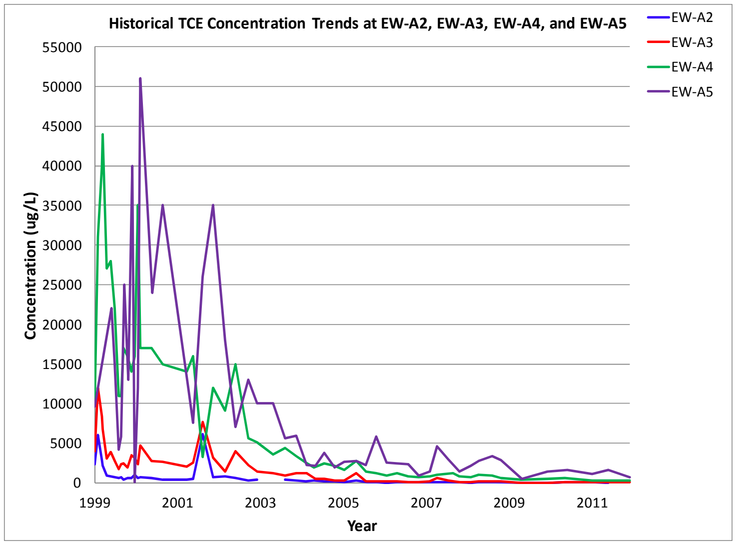
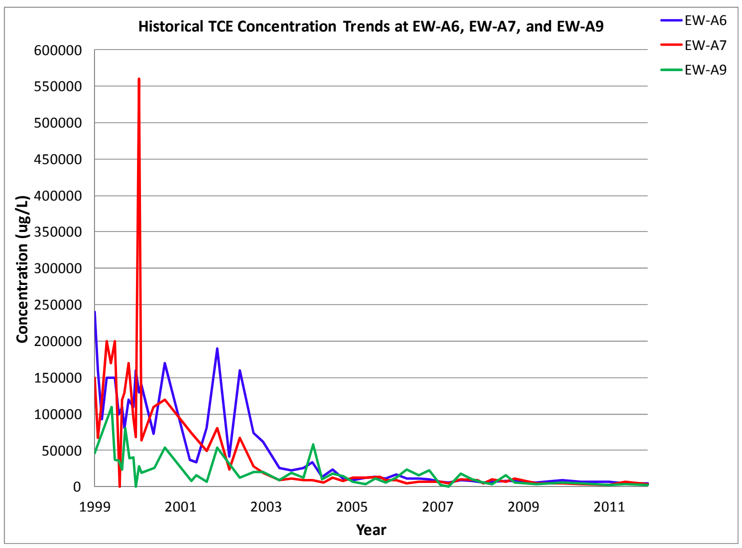


Figure 5. May 2012 Dissolved TCE, PCE and CCl_4 Concentrations in Groundwater in Hydrogeologic Unit B in Area A





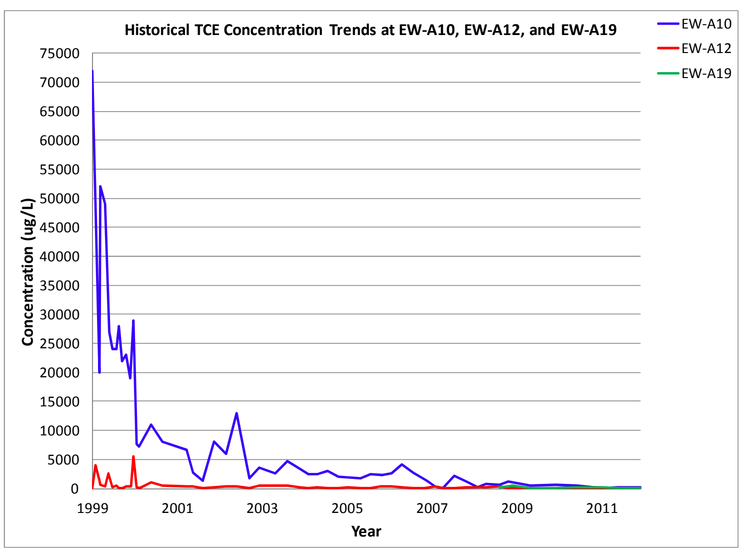


Figure 6. Historical TCE Concentration Trends in Area A Extraction Wells in the Study Area

2.1.2 Remedial Activities. Several remedial actions have been completed to address impacted soil and groundwater within Area A. Those activities pertinent to this investigation and identified study area within this report are described below.

Operable Unit 9. Contaminated soils at Area A were designated as Operable Unit 9 (OU 9) under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). In 1999, a soil excavation removal occurred in Area A (Sites 1, 2, and 3) to address the contaminated soil. A human health risk assessment and ecological risk screening were performed to determine potential risks to humans and environmental receptors from surface and subsurface soil at Area A. Based on an anticipated industrial development future land use scenario, a calculation of potential impact to groundwater, and the potential erosion and run-off of contaminated soil to the nearby unnamed tributary to little Neshaminy Creek, cleanup goals were calculated (Table 4). Excavations occurred in two locations at Site 1, three locations at Site 2, and one location at Site 3 (Figure 2). The TI waiver zone and target area for source treatment in Area A is located just east of Site 1. The majority of Excavation 1B lies within the proposed study area, and a small portion of this excavation lies within the TI waiver zone at Area A. Details of the excavation activities are outlined in Table 5. After the initial excavation was completed, additional sampling and excavation were conducted until remedial cleanup goals were met. The result of each excavation was that there were no further human health risks for the reasonably anticipated land uses. In June 2000, the Navy and U.S. EPA issued a ROD for OU 9, which found that no further action was necessary to address soil in Area A.

Table 4. Cleanup Goals for 1999 Removal Action at Area A

Site	Parameter	Cleanup Goal
Site 1 Excavation 1A	TCE	60 µg/kg[1]
	Antimony	113 mg/kg
	Cadmium	76 mg/kg
	Chromium	16,161 mg/kg
Site 1 Excavation 1B	TCE	60 µg/kg[1]
	Antimony	113 mg/kg
	Cadmium	76 mg/kg
	Chromium	16,161 mg/kg
	Thallium	14 mg/kg
Site 2 Excavation 2A	Antimony (Surface Soils)	50 mg/kg
	Lead (Surface Soils)	1,000 mg/kg
	Antimony (Subsurface Soils)	113 mg/kg
	Lead (Subsurface Soils)	1,750 mg/kg
Site 2 Excavation 2B	Benzo(a)anthracene	2,300 µg/kg
	Indeno(1,2,3-cd)pyrene	1,100 µg/kg
Site 2C	Benzo(a)pyrene	78,000 µg/kg
Site 3	Anthracene	540 µg/kg
	Benzo(a)anthracene	2,300 µg/kg
	Benzo(a)pyrene	2,500 µg/kg
	Fluoranthene	5,000 µg/kg

(1) The current U.S. EPA regional screening level for TCE and the impact to groundwater pathway is 1.8 µg/kg.

Table 5. Details of Soil Excavation Activities at Area A

Site	Total Volume Excavated (yd^3)	Depth Excavated	Conclusion
1	~3,600	Excavated to bedrock or 12 ft bgs	No remaining contaminants of concern (COCs) for reasonably anticipated land uses
2	~900	Surface soils excavated to 2-3 ft bgs; subsurface soils excavated up to 4-7 ft bgs	No remaining risks to human health in surface/subsurface soils; potential risk to ecological receptors
3	~380	Excavated to roughly 2-3 ft bgs	No remaining risks to human health in surface/subsurface soils

Operable Unit 1A. Groundwater was also identified as a media of concern at Area A and designated as OU 1A under CERCLA. The remedial action objective stated in the ROD for OU 1A is to restore contaminated groundwater to a level that is protective of human health and the environment and consistent with drinking water standards and to prevent downgradient migration to the municipal production well, WMA-26. However, these remedial action objectives are waived for TCE, PCE, and CCl_4 within the TI waiver zone. MCLs for other COCs must be met even within the TI waiver zone, and the ROD requires that contamination and DNAPL inside of the TI waiver zone be contained.

The ROD specifies groundwater extraction and treatment as the remedial action, and also includes the use of institutional controls to prevent the use of Area A groundwater as long as it presents an unacceptable risk, and to protect the integrity and effectiveness of the extraction well network. The institutional controls include the use of deed restrictions for property transferred from NAWC Warminster, and the use of municipal ordinances to restrict well drilling on private properties. Implementation of the groundwater extraction and treatment began in 1999 in Area A. By design, and as stated in the Area A ROD, the diffuse contaminant plume not contained by the extraction well network in Area A is captured by the downgradient municipal supply well (WMA-26).

The current Area A GWETS includes a total groundwater extraction rate of approximately 53 gallons per minute (gpm) from 12 active extraction wells, and treatment for VOCs using an air stripper and liquid-phase granular activated carbon (LGAC). While not identified as a COC, ion exchange treatment is also included for hexavalent chromium based on the GWETS discharge limits identified in the National Pollution Discharge Elimination System permit.

An evaluation of the historical groundwater concentration trends estimated that the current GWETS system will be operational for an additional 34 to 48 years to reduce TCE concentrations below the MCL in the source area. However, if source area treatment is applied, it is estimated that the GWETS would need to continue operation for an additional 15 to 25 years after treatment to reduce TCE concentrations below the MCL (Battelle, 2011).

2.2 Area C

Area C is located along Kirk Road and Newtown Road in the north-central portion of the former NAWC Warminster, and was defined as Sites 4 and 8 and nearby locations where hazardous substance releases may have resulted in groundwater contamination (Figure 7). Site 4 was a 7-acre area located north of the former main runway and south of Kirk Road. Several trenches were reportedly operated from 1966 to 1973 to dispose of non-industrial solid waste, paints, waste oils, waste metals, construction debris, solvents, and sewage sludge from the sewage treatment plant. Site 8 was located at the northeastern end of the old runway and was used as a fire-training area from 1961 to 1988. In addition, an area of the runway immediately south of the fire-training area was used to test the resistance of aviation suits to fire. This area consisted of a corrugated metal building where flight suits were passed through flames to test the durability of the suits (Tetra Tech NUS, 2007).

Historical activities resulted in contamination impacting soil and groundwater, as well as sediment and surface water in unnamed tributaries that collect drainage from Area C along the former Base boundary. Under the CERCLA program, Area C was divided into four OUs. OU-2 addressed contamination of domestic well water for residences near the Base; OU-3 addressed Area C groundwater; OU-5 addressed soil, surface water, and sediment associated with Site 8; and OU-6 addressed soil, sediment and surface water associated with Site 4. OU-2 was closed by connecting impacted homes to the municipal water supply system, and OU-5 and OU-6 were closed by excavating and removing impacted soils; OU-3 remains the only active operable unit at Area C.

The portion of Area C west of Site 8 has been transferred and redeveloped for residential use (a portion of Ann's Choice Retirement Community in the vicinity of Site 8 and other residential development west of Site 8). Other property adjacent to and in the vicinity of Site 4 is currently an open-space recreational park for Warminster Township.

2.2.1 Current CSM. A comprehensive geophysical investigation was conducted by the U.S. Geological Survey at Area C in 2007-2008 (USGS, 2008). The goal of this investigation was to describe the lithology at Area C and to provide information about water-bearing fractures within the bedrock beneath the site. Historical investigations have shown that residual soils (mixtures of silt, clay, and sand) overlie highly weathered bedrock that starts at approximately 5 to 15 ft bgs. The weathered bedrock gradually transitions into competent bedrock of the Stockton Formation, which consists of alternating lithologic units of predominantly fine-grained gray to brown arkosic sandstone and red-brown siltstone/mudstone (Figures 8 and 9). Within Area C, bedrock strikes to the northeast and dips to the northwest. In general, the majority of bedrock fractures were identified between the depths of 21 to 40 ft, and the fractures became sparser as the depth increased. The results of the fracture analysis are presented in Table 6.

Area C has been divided into shallow and deep hydrogeologic units. The shallow unit is comprised of sandstone and is the primary unit in which contaminant concentrations are observed. The deep hydrogeologic unit is defined as water-bearing bedrock beneath the shallow hydrogeologic unit, and typically exhibits artesian conditions. Shallow groundwater flow across Area C is to the north in the general direction of the slope of ground surface topography and has been affected by operation of the groundwater extraction system. Groundwater elevations collected during the 2012 annual sampling event (May 2012) are shown on Figure 10.

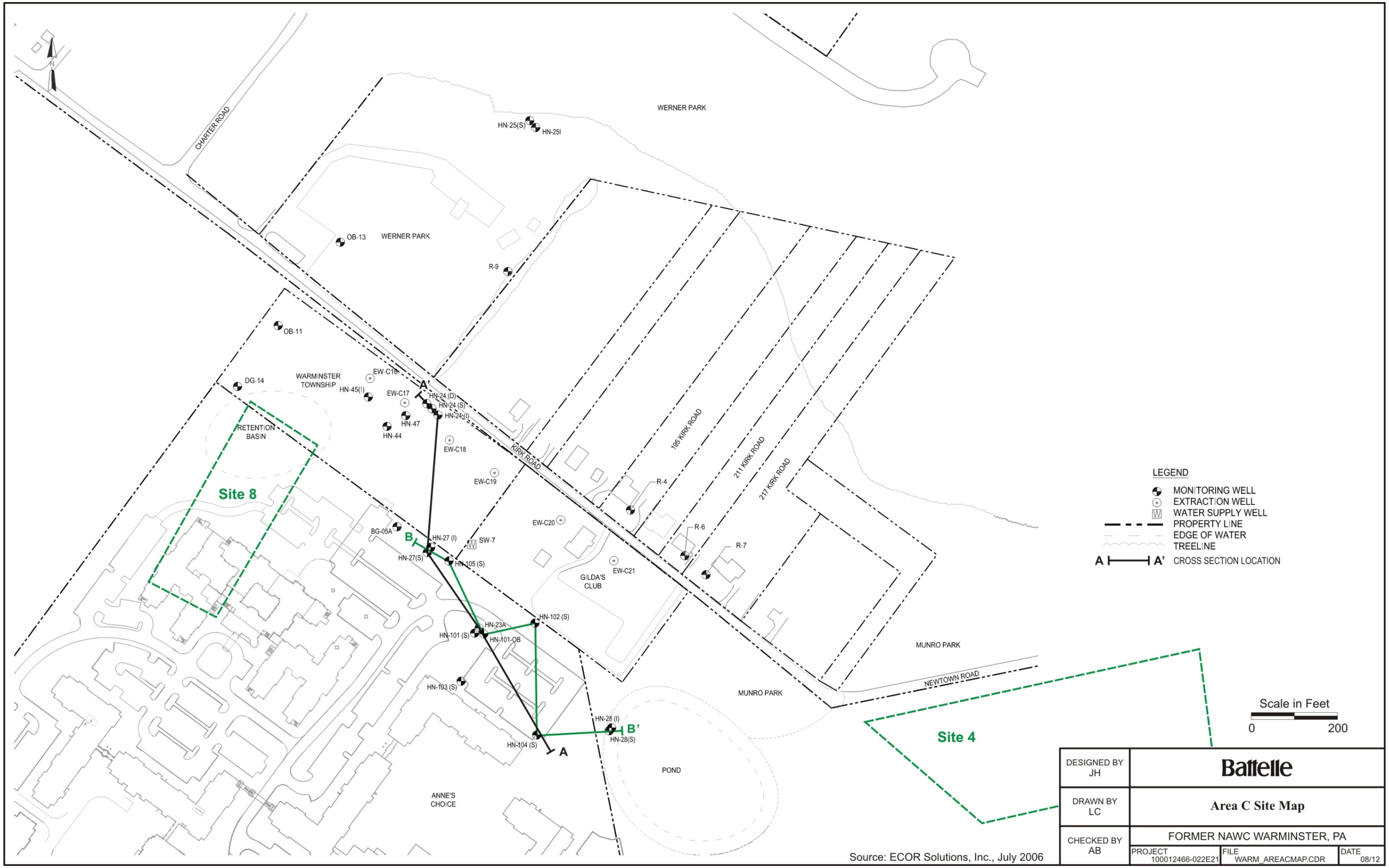


Figure 7. Area C Site Layout

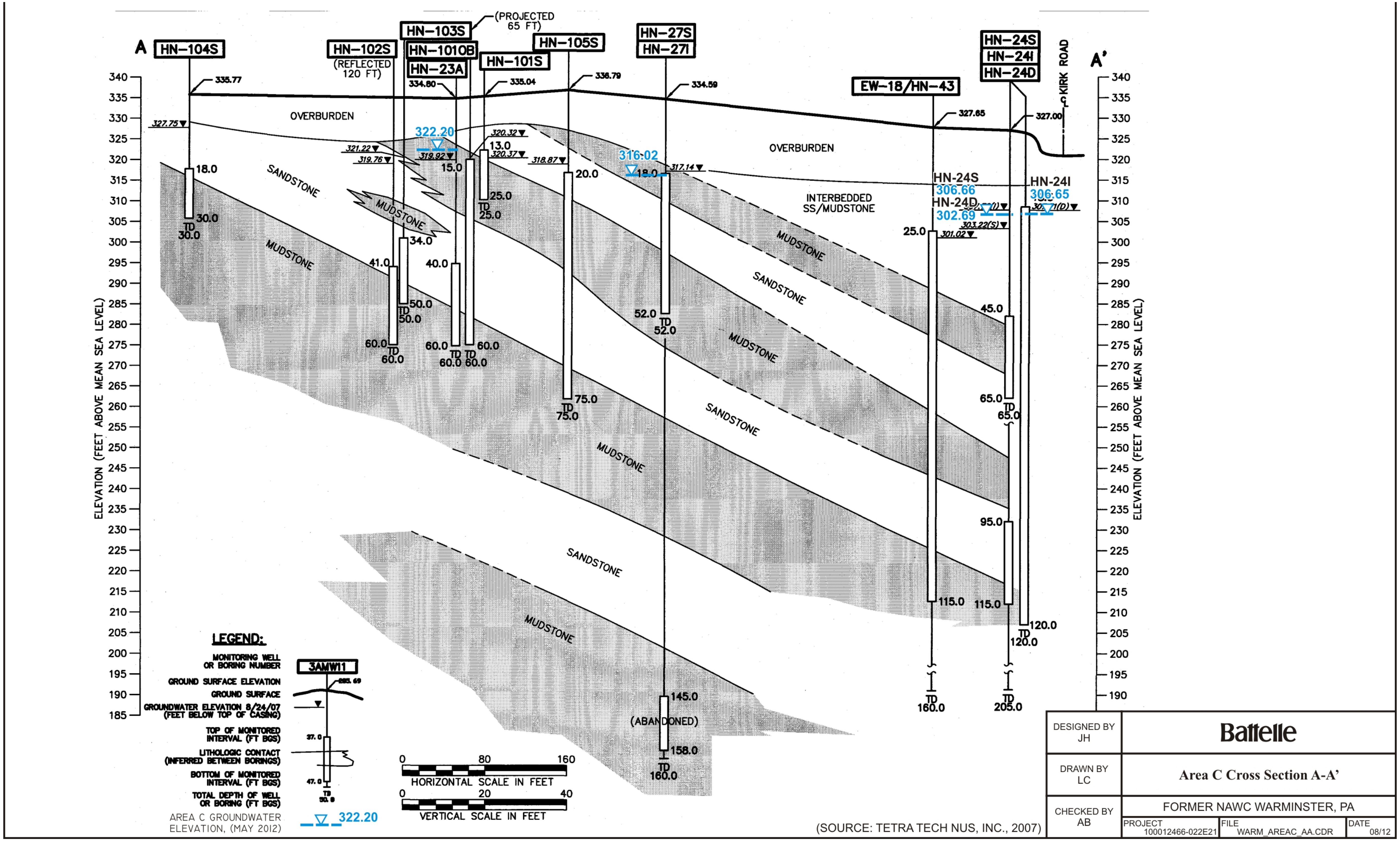


Figure 8. Area C Cross-Section A-A'

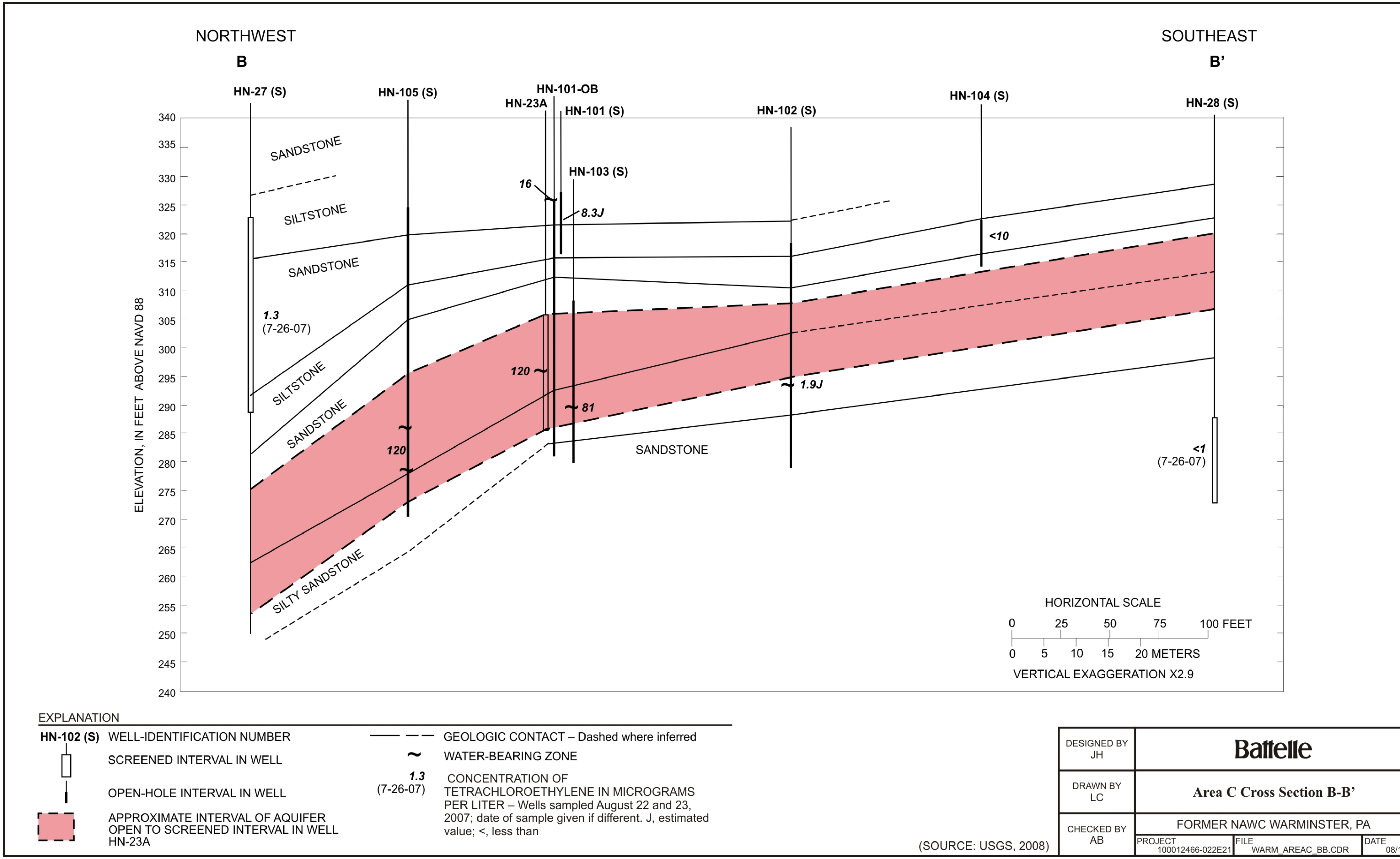


Figure 9. Area C Cross-Section B-B'

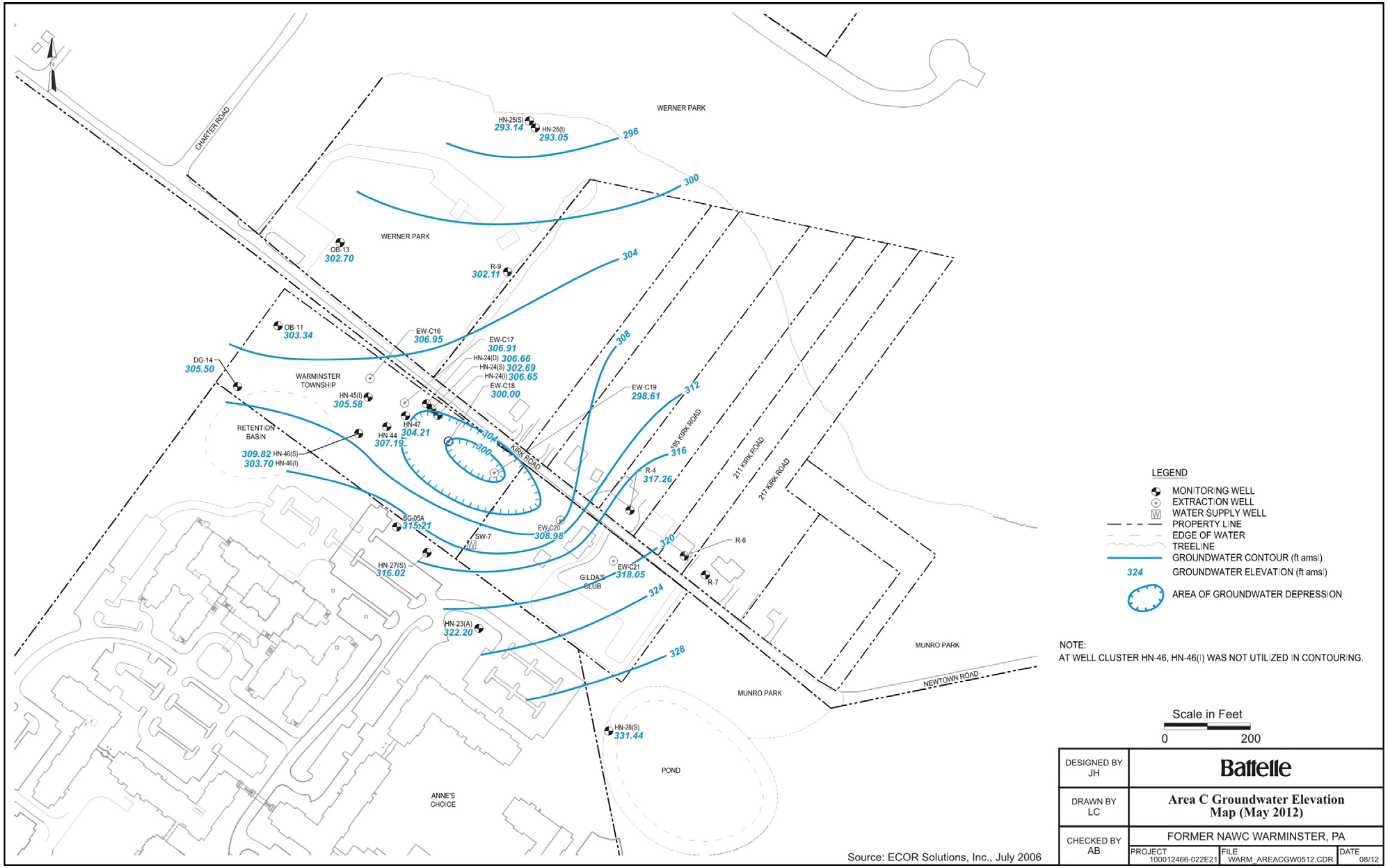


Figure 10. Area C Groundwater Elevation Map, Shallow Hydrogeologic Unit (May 2012)

Table 6. Fracture Zones in Area C

Well	Fracture Zones (ft bgs)		
	12-30 ft bgs	30-60 ft bgs	60-70 ft bgs
HN23A	None	47	NA
HN101-0B	17-20, 25, 28-30	47-48, 51, 54, 57	NA
HN101-S	19, 21, 23	NA	NA
HN102-S	22-25	30-32, 36-37, 39-40, 47-48, 52, 54	NA
HN103-S	None	32, 36, 38, 40, 45-47	NA
HN104-S	21, 27	31	NA
HN105-S	29	36, 43, 58	70

NA – not applicable; borehole does not extend to this depth.
(U.S. Geological Survey, 2008)

Dissolved PCE is the main COC at Area C. The majority of contamination is found in shallow hydrogeologic unit wells at relatively shallow depths of less than 50 ft. Table 7 provides concentrations of PCE at the 12 monitoring wells sampled during the May 2012 sampling event at Area C, and Figure 11 illustrates an isoconcentration contour map for PCE in the shallow hydrogeologic unit. Four wells had concentrations of PCE that exceeded its MCL of 5 µg/L. The majority of MCL exceedances occurred at extraction wells (EW-C18, EW-C19, and EW-C20). Concentrations of PCE at EW-C18 have increased since the baseline sampling event in 1999; however, concentrations are highly variable (Figure 12). Concentrations of PCE at the remaining Area C extraction wells are currently lower than those collected during the initial sampling event.

Table 7. May 2012 PCE Concentrations in Area C

Well ID	Hydrogeologic Unit	PCE (µg/L)
EW-C17	Shallow	0.26 J
EW-C18		**19**
EW-C19		**11**
EW-C20		**7.4**
DUP-6 (EW-C20)		**7.8**
EW-C21		0.75 J
BG-05A		4.1
HN-23A		**65**
HN-25I		2.1
HN-27S		0.94 J
HN-28S		0.20 U
R-9		1.7
WMA-13	**NA**	0.20 U

Bold indicates concentration exceeds the MCL of 5 µg/L.
J – estimated value.

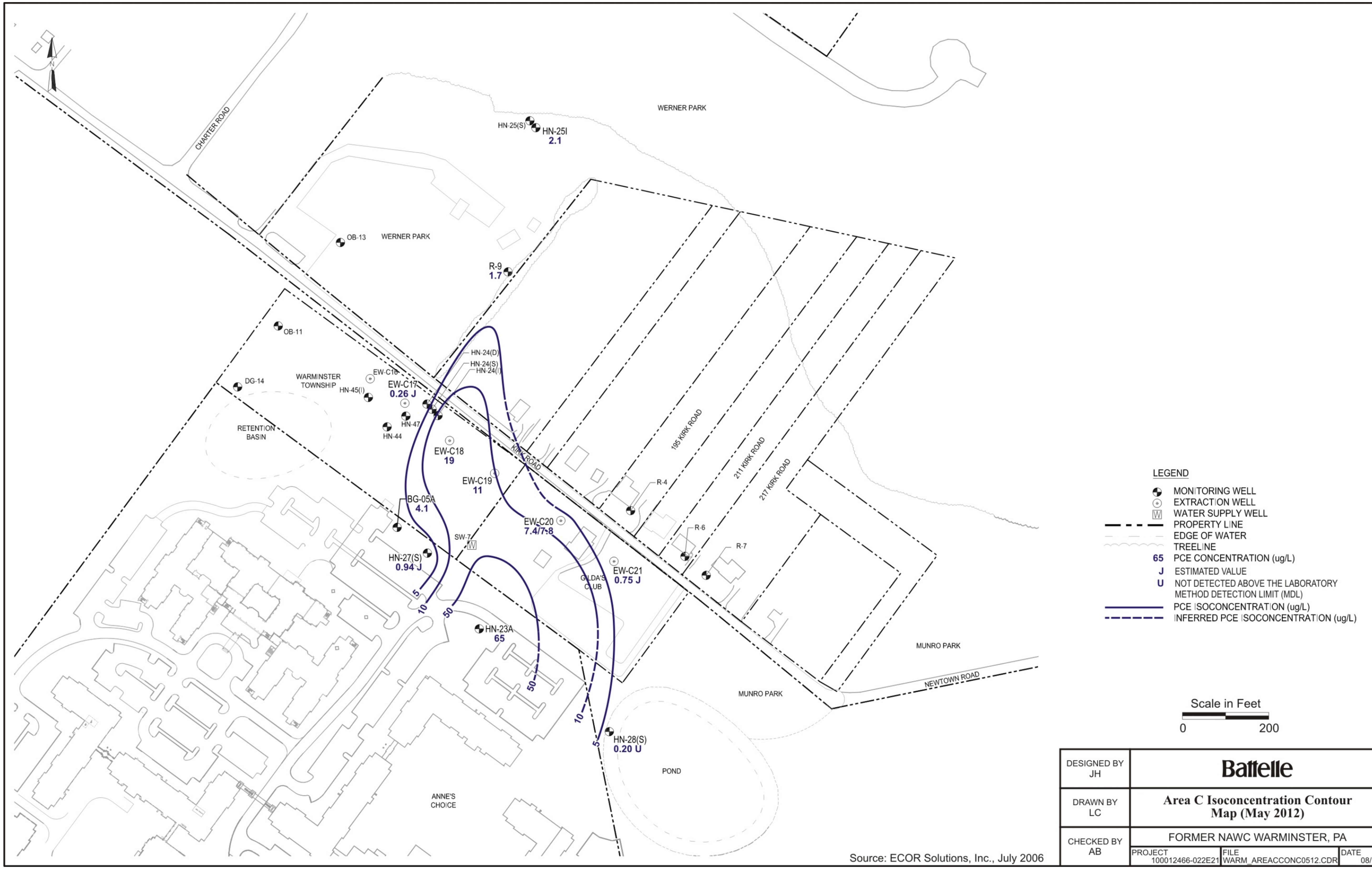


Figure 11. Area C PCE Isoconcentration Contour Map, Shallow Hydrogeologic Unit (May 2012)

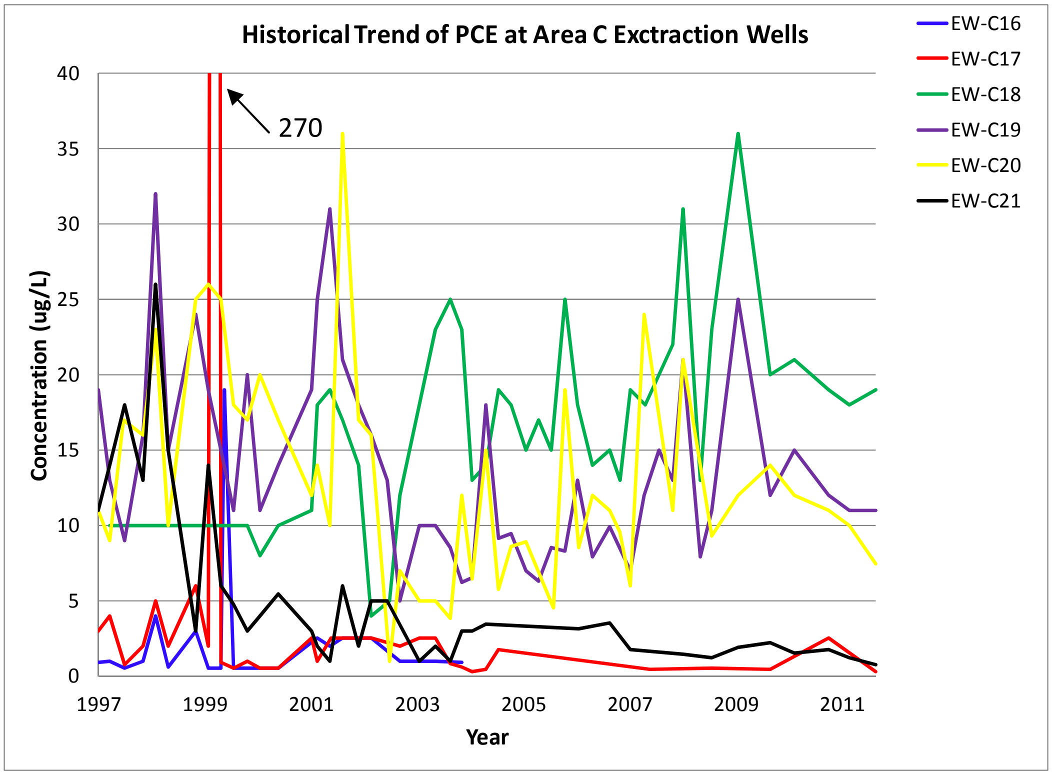


Figure 12. Historical PCE trends at Area C Extraction Wells

In May 2012, the maximum PCE concentration of 65 µg/L was detected at HN-23A, which is approximately 400 ft from the nearest extraction well. Detections of PCE in this well have previously been in excess of approximately 300 µg/L (see Figure 13), and may indicate that a potential upgradient source of PCE contamination still exists; however, detections since June 2011 have been below 100 µg/L.

It should be noted that municipal production well WMA-13 is downgradient of Area C, and no contaminants have been detected above MCLs in this well since monitoring began in this well.

2.2.2 Current Remedial Activities. Several remedial investigations have been performed to attempt to identify the source for groundwater contamination at Area C. In addition to Sites 4 and 8, other areas of concern were also investigated, including the former maintenance area located immediately east of Site 8, the leach field associated with the former base commander's residence, and an old pistol firing range; however, none of these discrete investigations found significant levels of contamination or provided evidence suggesting a potential source for the PCE contamination in groundwater (Tetra Tech NUS, 2007).

The remedial action objective stated in the ROD for OU-3 (Area C) is to restore contaminated groundwater attributable to Area C to a level that is consistent with drinking water standards, and to a level that is protective of human health and the environment. The ROD for Area C also specifies groundwater extraction and treatment as the remedial action. Implementation of the groundwater extraction and treatment began in 1996. An Explanation of Significant Differences also was signed for Area C, which adds institutional controls as an additional component of the remedy to prevent use of groundwater that presents an unacceptable risk to human health, and to protect the integrity and

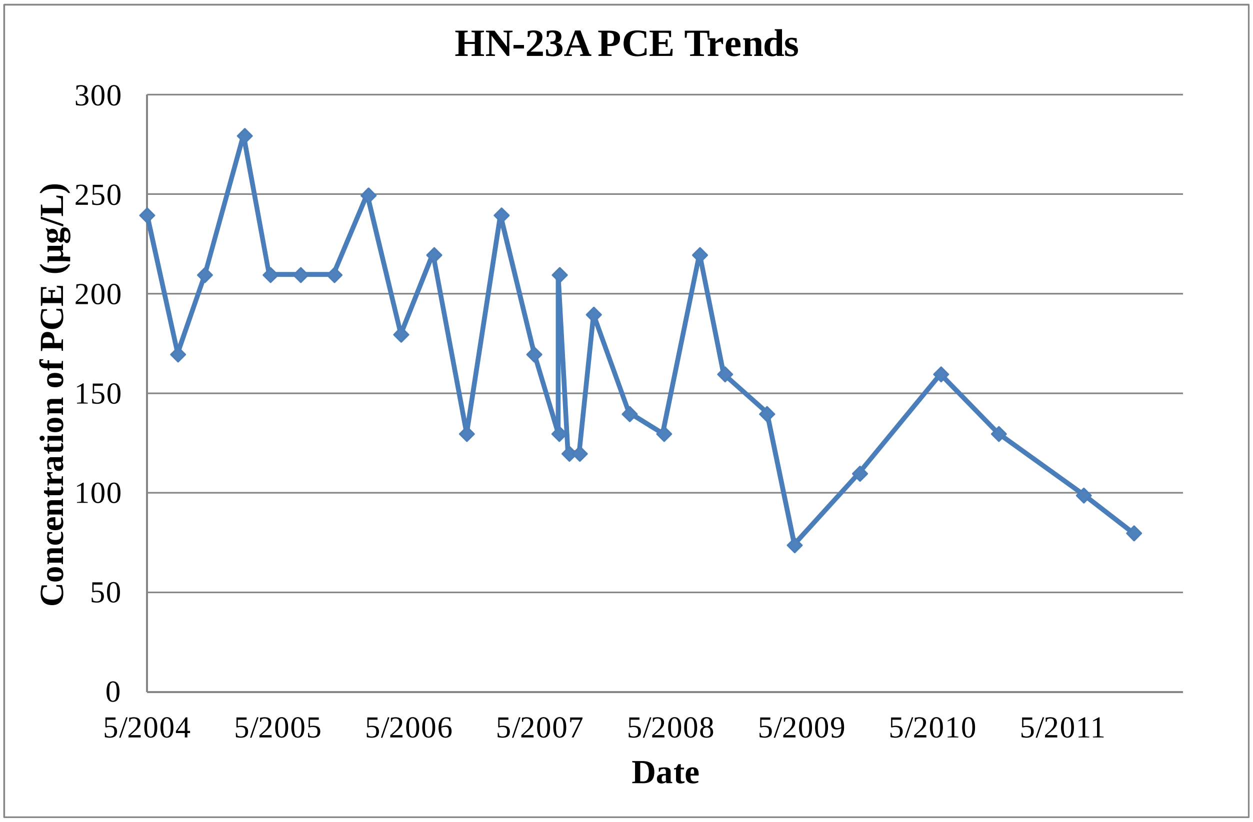


Figure 13. Historical PCE trends at Well HN-23A at Area C

effectiveness of the extraction well network which was constructed in accordance with the ROD. The institutional controls include the use of deed restrictions for property transferred from the NAWC Warminster facility, restrictions on the use of water from existing wells and future installation of wells located on the NAWC and the use of municipal ordinances to restrict well drilling on private properties.

The design of the extraction well system at Area C was developed by the Technical Evaluation Group (TEG), a technical committee consisting of hydrogeologists representing the Navy, U.S. EPA, Pennsylvania Department of Environmental Protection, and the USGS, which was formed to focus on NAWC Warminster hydrogeologic issues. The well locations were adjusted in the field as drilling progressed based on TEG direction, and the pumping rates were established by the TEG based on the results of yield tests and capture zone projections (Halliburton NUS, 1994). Based on this effort, a combined pumping rate of 59 gpm in six wells was specified as being adequate for containing groundwater contamination associated with the Area C source area. Two wells at the northwest side of the extraction network (EW-C16 and EW-C17) were later turned off because historical groundwater samples collected from these wells indicated they were capturing groundwater with no measurable contaminant concentrations. Groundwater modeling was subsequently used to demonstrate capture of groundwater contamination at Area C. The modeling simulations suggested that a combined pumping rate of 27 gpm, which was similar to typical operational pumping rates, would contain the Area C plume. Area C groundwater is pumped from the area adjacent to Kirk Road on the north side of the runway to the GWETS, which is on the other side of Jacksonville Road (Figure 1). A brief description of the GWETS is presented in Section 2.1.2.

In 2006, the Area C extraction wells were pumping at a combined rate of approximately 22 to 37 gpm, whereas initial design suggested a combined rate of 47 gpm, which does not include wells EW-C16 and

EW-C17. As stated earlier, these wells were turned off after monitoring data indicated that they were no longer capturing contaminated groundwater. The ROD for Area C states that the extraction wells shall be sufficient to prevent migration of and capture all contaminated groundwater associated with Area C. The reduced pumping rate of approximately 22 to 37 gpm is similar to the previous modeling data which suggested pumping at 27 gpm would contain the elevated groundwater contaminant concentrations.

2.2.3 Recent Area C Source Assessment Investigation. In December 2002, monitoring well HN-23A was installed as a replacement monitoring well for HN-23S, which had been abandoned during construction of the Ann's Choice Retirement Community. Elevated PCE concentrations (up to approximately 300 µg/L) were observed in this replacement well. HN-23A is located upgradient of the line of extraction wells associated with Area C, and PCE concentrations at the extraction wells have been much lower during recent sampling (< 20 µg/L). Based on this information, the area around HN-23A, formerly identified as disturbed ground noted in historical Environmental Photographic Interpretation Center photos, was the focus of the recent Area C source assessment investigation conducted in 2007 by Tetra Tech NUS, Inc. This area is currently a parking lot at the Ann's Choice Retirement Community. The primary objectives of the Area C source assessment were to (1) delineate the extent of groundwater contamination in the vicinity of HN-23A, and (2) characterize any contaminant source areas identified.

A total of six monitoring wells (HN-101S, -102S, -103S, -104S, -105S, and -101OB) were installed to delineate groundwater contamination in the vicinity of HN-23A. Wells HN-101S through HN-104S were installed as 2-inch diameter polyvinyl chloride wells screened across the selected water-bearing zone, and wells HN-105S and HN-101OB were installed as 6-inch diameter open borehole wells. An 8-hour pumping test was performed in June 2007 at HN-101OB, and groundwater samples were collected at wells HN-23A, HN-101S, HN-102S, HN-103S, HN-104S and HN-101OB before and after the pump test. Samples were also collected from all wells again in August 2007 after installation of HN-105S.

Results from the groundwater sampling conducted in conjunction with the pumping test indicated that PCE was detected in all wells except HN-104S, and TCE and DCE were detected only at HN-23A and HN-105S. TCE and DCE are commonly detected as breakdown products of PCE, and their presence in HN-23A and HN-105S is likely an indication that historical source treatment (injection of HRC®) in HN-23A has resulted in some breakdown of PCE into these associated daughter products. The lack of TCE and DCE in other wells in the area indicate that neither TCE nor DCE were historically disposed of as waste products in this area (Tetra Tech NUS, 2007).

The highest concentrations of PCE before and after the pump test were detected in HN-23A, where concentrations increased from 130 to 210 μg/L during the test. HN-103S, located south (upgradient) of HN-23S, had the next highest PCE detections, at 75 and 110 μg/L detected before and after the pumping test. No PCE was detected in the well furthest upgradient (HN-104S), and only trace levels of PCE (< 2 μg/L) were detected in HN-102S, located east of the pumping well. This pattern of contamination, along with the northerly groundwater flow direction, suggests that the PCE is likely originating from an area south of HN-23A and HN-103A (Tetra Tech NUS, 2007).

A comparison of PCE concentrations collected from various aquifer depths during the study indicates that higher PCE concentrations are observed at deeper depths in this area. HN-101S monitors a shallower zone (13 to 25 ft bgs) and a lower PCE concentration was detected (19 to 26 μg/L). Higher PCE concentrations were detected at HN-23A (130 to 210 μg/L), which monitors a deeper portion of hydrogeologic unit A, from approximately 40 to 60 ft bgs. The pattern of higher PCE concentrations at deeper depths in this area suggests that the source of the contamination is not in the immediate vicinity of this well cluster, but is located some distance upgradient/updip (Tetra Tech NUS, 2007). Figure 9 illustrates that this deeper elevated PCE contamination is primarily confined within the sandstone/ mudstone stratigraphic unit within which HN-23A is screened.

A soil gas survey was also conducted in the vicinity of HN-23A as part of the investigation in an attempt to locate residual sources of PCE. A total of 60 sampling locations were selected surrounding HN-23A. Soil gas samples were field-analyzed for VOCs using a photoionization detector (PID), with a maximum reading of 1.5 parts per million. The pattern of low soil gas survey results did not indicate the local presence of a discrete source for the PCE contamination found in groundwater in this area (Tetra Tech NUS, 2007).

Section 3.0: AREA A SOURCE TREATMENT OPTIMIZATION DESIGN ACTIVITIES

The objective of source treatment within Area A is to reduce the life-cycle cost and timeframe associated with cleanup of the Area A groundwater, including the area within the TI waiver zone. This section presents a summary of previous recommendations associated with Area A source treatment, a summary of activities required to support design of the Area A source treatment, and general data quality objectives (DQOs) associated with these activities.

3.1 Overview of Previous Source Area Treatment Optimization Recommendations

An evaluation of source area treatment options for Area A was performed to determine whether supplemental source area treatment could result in reduced life-cycle costs and remedial timeframe for operation of the GWETS associated with Area A (Battelle, 2011). The data trend evaluation completed as part of this study predicted that the operation of the existing GWETS may be required for up to another 48 years before the remedial goals are achieved at Area A. It should be noted, however, that a continued operational timeframe of 30 years was used for costing purposes in this report, consistent with standard cost estimating guidance (U.S. EPA, 2000). The 30-year net present value (NPV) for continuing LTM and operation of the optimized GWETS was estimated to be $5.4 million.

Based on the site-specific evaluation presented in Appendix A of the *Remedial Action Evaluation Report for Operable Unites 1A, 3, and 4 Groundwater Treatment System at NAWC Warminster, Pennsylvania* (Battelle, 2011), ISCO using activated sodium persulfate or Fenton's reagent was identified as a viable alternative for source zone treatment in Area A. A preliminary cost analysis indicated that the estimated cost for conducting ISCO treatment is approximately $810,000. It is not anticipated that final remediation goals would be achieved immediately following the source area treatment, therefore continued operation of the pump and treat system would be required until the goals are achieved. If source area treatment is applied (i.e., ISCO), it was estimated that the pump and treat system would need to continue to operate for an average of 15 additional years after treatment to a maximum of 25 additional years after treatment to reduce TCE concentrations below the MCL (Battelle, 2011). Therefore, it is estimated that 5 to 15 years of GWETS operation may be saved if source area treatment is implemented. This implementation would result in a savings of approximately $750,000 to $2.1 million related to early shutdown of the GWETS as a result of source area treatment. Therefore, it was determined that source area treatment can reduce the life-cycle costs and overall timeframe for achieving remedial goals at Area A (Battelle, 2011).

A phased approach was recommended for further evaluation of ISCO as a viable source area treatment technology for Area A. This approach includes the following steps:

- Perform discrete depth groundwater sampling to identify target sample locations for bench testing and to support design of a pilot-scale ISCO study.
- Select discrete depth groundwater sample intervals based on soil screening results within the source area to refine the vertical treatment zone.
- Collect soil and rock core samples and groundwater samples from within the source area to be used for bench-scale testing of the ISCO technology and evaluation of residual contamination present in the unsaturated zone soil.
- Conduct a series of ISCO bench-scale tests using various oxidants to determine effectiveness of the ISCO technology in treating the COCs.
- Design and conduct ISCO pilot test.

- Perform continuous field screening during pilot test injection point installation to confirm pilot test design parameters by evaluating chemical concentrations and lithology of soil cores.
- Design and conduct full-scale ISCO treatment.

The implementation of additional source area sampling, completion of an ISCO bench test, and preparation of a design basis for pilot- or full-scale ISCO are the specific tasks discussed within this implementation plan. Each of these activities is discussed in the following sections.

3.2 Area A Source Area Treatment Design Activities

Activities to be conducted to support the stated objective for Area A include soil and groundwater sample collection for ISCO bench testing, discrete depth groundwater sampling, and preparation of a design basis for a pilot- or full-scale ISCO treatment. A general discussion of each activity is provided below. This plan will be followed by Area-specific work plans, quality assurance project plans (QAPPs) (where applicable), and reports specific for the activities.

Discrete Depth Groundwater Sampling. Discrete-depth groundwater sampling will be conducted for VOC analysis from wells within the proposed study area to better define the treatment zone and to provide additional information for designing the pilot- and full-scale treatment. Borehole flow measurements will be collected prior to sampling to determine the direction and rate of groundwater movement within study area wells, and the data will be used to optimize the depth(s) of sample collection. A separate work plan will be developed to document the sampling procedures and wells/depths to be sampled. Sample collection from selected extraction and monitoring wells will be performed using passive diffusion bag (PDB) samplers, according to the sampling procedures outlined in the current Sampling and Analysis Plan (H&S Environmental, 2011). The information presented in Section 2 of this report (well construction, fracture location, and VOC concentration data) will be used to identify the preferred sample locations based on hydraulically-active fractures in monitoring wells and extraction wells within Area A.

Groundwater and Soil/Rock Core Collection for Bench Testing and Unsaturated Zone Evaluation. Groundwater and soil/rock core samples will be collected from the source area for bench-scale testing and to evaluate the potential for residual contamination present in the unsaturated zone soil, weathered bedrock, and bedrock. Soil/rock cores from the unsaturated zone will be screened with a PID, and samples will be collected for laboratory VOC analysis from intervals with elevated PID readings.

The bench-scale treatability study will be performed using rock and groundwater samples from the source zone to determine operating parameters for potential chemical oxidants including hydrogen peroxide and activated persulfate. A separate work plan and QAPP will be developed to document the procedures for collecting the rock core and groundwater samples, as well as for performing the sample analyses and implementing the bench test.

The soil/rock cores will be conducted continuously from land surface into the mudstone unit at the base of hydrogeologic unit B, with samples collected at discrete intervals based on physical evaluation of the soil/rock cores, geophysical logs (if any), the results of vertical profiling, and well drilling logs for existing wells. The soil/rock core sampling will also evaluate the presence of contaminants in the unsaturated zone under pumping or non-pumping conditions, and the potential for migration of those contaminants to groundwater.

The bench testing will include soil oxidant demand (SOD) analysis to evaluate the decomposition of activated persulfate in the presence of site rock pieces. By comparing the behavior of persulfate under different conditions (activated and non-activated persulfate, both with and without site rock), the test will evaluate persulfate kinetics and persistence and calculate the portion of persulfate that is lost to non-target demand (i.e., SOD). A series of bench-scale jar tests using persulfate at various concentrations along with different activators such as iron, alkaline, and peroxide will be completed to determine the optimum concentration and activation mechanism to remove the COCs at the site. Additionally, a base buffering test will be completed to determine the quantity of base that would be required to reach conditions favorable for the autodecomposition of persulfate.

For hydrogen peroxide, a stability test will be completed to evaluate the rate of decomposition of hydrogen peroxide in the presence of site soils with and without different stability agents. This test accounts for subsurface transition metals in addition to non-target reactions. Different concentrations, availabilities and types of transition metals in the subsurface will affect the rate of hydrogen peroxide decomposition, its persistence in the subsurface, and the volume and radius of influence it can be expected to treat. The use of stability agents, including organic chelates such as ethylenediamine tetraacetic acid or citric acid, will be evaluated to determine impact on subsurface persistence of the oxidant and reaction rates. The ISCO bench test will also evaluate the rate and volume of gas generated during application of Fenton's reagent to address key design issues.

The bench tests will also evaluate changes in subsurface geochemistry that could affect pump and treat operation (including the potential for metals mobilization), and effectiveness of each oxidant in treating the COCs in the presence of the fulvic acids that have been identified in groundwater at the site.

Results of bench-scale testing will be incorporated into the CSM and used to determine whether or not source area treatment using ISCO should be pursued at pilot or full scale, and if so, which oxidant is the most cost-effective and technically practical for use at Area A. A summary report presenting the results and recommended approach will be prepared.

Design Basis for ISCO Pilot or Full Scale Test. Provided that the laboratory treatability study indicates that ISCO would be technically practical and cost-effective to treat the COCs present at Area A, a pilot test will be recommended. Results of the bench testing and discrete depth well sampling will be used to develop the design basis for pilot- or full-scale source area treatment with ISCO. The design basis will specify the oxidant and dosing for the pilot based on results from the bench testing. In addition, the design basis also will include recommendations for well spacing, injection/extraction/recirculation rates and methodology, injection logistics and monitoring to ensure effectiveness and to minimize potential impacts to the GWETS and downgradient supply wells.

3.3 Data Quality Objectives

U.S. EPA's seven-step DQO process was used as guidance during this initial planning stage for the evaluation outlined above. The general DQOs associated with Area A activities are presented below. More specific DQOs will be developed, as appropriate, for each individual work plan and/or QAPP to be prepared for specific tasks.

- ***State the problem.***
  Groundwater pump and treat has been ongoing at Area A since 1999. Under the current pump and treat remedy, cleanup of groundwater at Area A is expected to continue for up to another 48 years before the remedial goals are achieved. A preliminary evaluation of source area treatment options indicates that aggressive source area treatment using ISCO may be a cost effective option to reduce life-cycle costs and the timeframe necessary to achieve the remedial goals. A more detailed understanding of contaminant distribution within the

fractured bedrock geology and treatability testing of ISCO for source area treatment is required to further evaluate the cost effectiveness of this aggressive source treatment option.

- ***Identify the decision.***
  Primary question: *Do results of the vertical plume delineation and ISCO bench test indicate that ISCO can effectively treat COCs under site specific conditions and lithology (using soil/rock and groundwater samples from the source area)?*
  Determine whether ISCO can effectively treat COCs in the presence of other naturally occurring material at the site (SOD, fulvic acids, etc.) and based on the vertical distribution of contaminants within the fractured bedrock, or whether other source treatment technologies should be evaluated.

  Supporting questions:
  Which fracture zones have the highest contaminant concentrations within the source area?
  Identify which fracture zones within the source area have the highest contaminant concentrations to identify the target treatment zone for pilot- or full-scale treatment.

  Is significant contaminant mass remaining in the unsaturated zone that could potentially migrate to groundwater?
  Determine if contaminant concentrations exceed U.S. EPA regional screening levels (RSLs) for impact to groundwater and may require further evaluation or treatment, or if no further evaluation is necessary.

  Which ISCO oxidant is best suited for treatment at the site?
  Based on results from the bench test, determine which oxidant (persulfate or hydrogen peroxide) is best suited to treat the COCs under site specific conditions, and determine what, if any activators or stabilizers are required to maximize efficiency of the ISCO treatment.

- ***Identify inputs to the decision.***
  Validated analytical results for VOC analysis will be used to determine the distribution of contaminants in groundwater and unsaturated zone soil within the source area. Existing geology/hydrogeology information will be used in conjunction with groundwater profiling results to determine target treatment zones for source treatment. Results from ISCO bench testing will be used to determine the most appropriate oxidant for the site and associated activators or stabilizers required to maximize efficiency of the treatment. U.S. EPA RSLs will be used for comparison to determine if further evaluation of VOC concentrations within the unsaturated zone soils is required.

- ***Define the study boundaries.***
  The horizontal boundaries of the study area are shown in Figure 2 and include the TI waiver zone within Area A and the area immediately surrounding that zone. The vertical boundaries include the unsaturated soil zone down to the mudstone unit at the base of hydrogeologic unit B.

- ***Develop a decision rule.***
  Select fracture zones with the highest concentrations as the target zones for future groundwater and soil/rock core sampling and for treatment during pilot- or full-scale implementation of source zone remediation.

If the analytical results from unsaturated zone soil sampling indicate that VOC concentrations exceed the RSLs for impact to groundwater, then further evaluate the site-specific factors affecting migration to groundwater in order to determine potential for unsaturated zone contamination to adversely impact groundwater in the future under non-pumping conditions. If the analytical results from unsaturated zone soil sampling indicate that VOC concentrations do not exceed the RSLs, then no further evaluation is required.

If treatability testing indicates that ISCO can effectively treat COCs, then proceed with developing a design basis for ISCO treatment using treatability study results and data obtained from well profiling and soil sampling. If treatability testing indicates that ISCO cannot effectively treat COCs, then evaluate other technology options for source zone treatment.

- ***Specify limits on decision errors.***
  Sampling will be completed within an area of known high VOC concentrations (TI waiver zone and surrounding area). The only specific limit for measurement error is selection of a laboratory that can achieve detection limits lower than the U.S. EPA RSLs. Data from the sampling that will be performed will be used to determine the distribution of this known contamination within the fracture network of the source area.

  Sampling design error will be minimized by collecting samples from several intervals (up to three) from each well within the study area, which includes every well located in the TI waiver zone and several wells surrounding the TI waiver zone to serve as boundary wells. However, it is acknowledged that the fractured bedrock formation within the study area does present uncertainty in the ability to accurately identify the distribution of contamination, regardless of the number of samples collected within the study area.

- ***Optimize the design for obtaining data.***
  The high degree of variability associated with contaminant distribution within the fractured bedrock geology within the source area requires collection of a greater number of samples. Because of this issue, samples will be collected from multiple vertical intervals within each well in the study area, with a maximum of three samples per well.

Section 4.0: AREA C REFINEMENT OF PLUME ARCHITECTURE ACTIVITIES

The objective of refining the plume architecture within Area C is to define the vertical distribution of contamination within the plume, which will be used to evaluate potential vapor intrusion risks to nearby buildings and optimize the groundwater extraction program. This section presents a summary of activities required to support these evaluation and optimization efforts, and general DQOs associated with those activities.

4.1 Area C Source Plume Architecture Refinement Activities

Activities to be conducted to support the stated objective for Area C include discrete depth groundwater sampling, evaluating the potential for vapor intrusion into nearby structures, and evaluating potential optimization strategies for groundwater extraction from the plume area. A general discussion of each activity is provided below. This plan will be followed by area-specific work plans and reports specific for the activities.

Discrete Depth Groundwater Sampling. Discrete-depth groundwater sampling will be conducted for VOC analysis from selected Area C extraction wells (active and inactive) and monitoring wells to determine the contaminant distribution within the open screen interval or borehole of each well. Borehole flow measurements will be collected prior to sampling to determine the direction and rate of groundwater movement within study area wells, and the data will be used to optimize the depth(s) of sample collection. A separate work plan will be developed to document the sampling procedures and wells/depths to be sampled. Sample collection from selected extraction and monitoring wells will be performed using PDB samplers, according to the sampling procedures outlined in the current Sampling and Analysis Plan (H&S Environmental, 2011). The information presented in Section 2 of this report (well construction, fracture location, and VOC concentration data) will be used to identify the preferred sample locations based on hydraulically-active fractures in the wells.

The data will be used to prepare a report that includes an interpretation and discussion of the relative plume mass contained in the various stratigraphic intervals, where the plume is present at the water table surface, and whether the spatial and vertical distribution of the plume could affect the potential for vapor intrusion into nearby structures. This spatial and vertical distribution data will support evaluation of potential modifications that may be made to the groundwater extraction program to increase efficiency of mass removal by the system. In addition, the data will be used to re-evaluate the potential for vapor intrusion into nearby structures. During the Area C source assessment (Tetra Tech NUS, 2007), it was determined that the strata that HN-23A is screened within outcrops to the southeast of HN-23A in the nearby parking area, beneath the nearby Ann's Choice condominium building (which was constructed with a soil vapor barrier), and beyond. Also, the pattern of PCE concentrations suggested that the source of contamination within Area C may be located some distance upgradient/updip of HN-23A (Tetra Tech NUS, 2007). This information, along with the new discrete depth sampling data, will be used to complete the above mentioned evaluations.

4.2 Data Quality Objectives

U.S. EPA's seven-step DQO process was used during this initial planning stage for this project. The general DQOs associated with Area C activities are presented below. More specific DQOs will be developed, as appropriate, for the Area-specific work plan.

- ***State the problem.***
  A GWETS is currently operating to extract and treat contaminated groundwater from Area C. Concentrations of PCE in groundwater extraction wells have been decreasing, with current concentrations <20 μg/L. When a replacement monitoring well (HN-23A) was installed upgradient of the extraction wells, higher PCE concentrations were identified (up to approximately 300 μg/L after installation of the replacement well); however, no known source could be located during the subsequent source assessment. The PCE concentration detected most recently in HN-23A was 65 μg/L in May 2012. Extraction of groundwater from the area downgradient of the highest concentrations may not represent the optimal groundwater plume remediation strategy. The presence of higher PCE concentrations in this upgradient area may result in the potential for vapor intrusion into nearby structures.

- ***Identify the decision.***
  What is the spatial and vertical distribution of PCE within Area C?
  Develop an updated CSM that identifies the relative plume mass contained in the various stratigraphic intervals and where the plume is present at the water table surface.

- ***Identify inputs to the decision.***
  Historical boring logs and borehole flow measurements, along with updated validated analytical results for VOC analysis from multiple intervals, will be used to determine the distribution of contaminants in groundwater.

- ***Define the study boundaries.***
  The horizontal boundaries of the study area include what has been defined as Area C under the cleanup program.   The vertical boundaries include the interval which comprises hydrogeologic unit A.

- ***Develop a decision rule.***
  Data obtained will be used to characterize the vertical distribution of contamination within the Area C groundwater plume, to evaluate the potential for vapor intrusion into nearby structures, and to evaluate potential optimization strategies for groundwater extraction from the plume area.

- ***Specify limits on decision errors.***
  Sampling will be completed within an area of known high VOC concentrations; therefore, no specific limits have been identified for measurement error. Data from the sampling that will be performed will be used to determine the distribution of this known contamination within Area C.

  Sampling design error will be minimized by collecting samples from several intervals at selected extraction wells and monitoring wells within the study area. However, it is acknowledged that the fractured bedrock formation within the study area does present uncertainty in the ability to accurately identify the distribution of contamination, regardless of the number of samples collected within the study area.

- ***Optimize the design for obtaining data.***
  The high degree of variability associated with contaminant distribution within the fractured bedrock geology requires collection of a greater number of samples. Based on this, samples will be collected from multiple vertical intervals within each selected well, with a maximum of three samples per well.

Section 5.0: PROJECT REPORTING AND SCHEDULE

Specific work plans and reports will be developed for the activities described in this optimization plan. This plan, as well as future work plans and reports, will be submitted for review by the TEG and Technical Review Committee. The following is a list of deliverables that will be prepared to support planning and reporting of the proposed activities. Table 8 shows the project schedule indicating the timing for planning, implementation and reporting.

- Work Plan for Area A and Area C Well Profiling
- Work Plan and Tier II UFP-QAPP for Area A Soil and Rock Core Collection and ISCO Treatability Testing
- Summary of Data Evaluation Associated with Area A
- ISCO Treatability Test Summary and Pilot Test or Full Scale Design Basis
- Summary of Data Evaluation Associated with Area C

Field activities associated with these deliverables include discrete depth profiling at Areas A and C and well drilling and soil/rock core collection at Area A. It is anticipated that the discrete depth profiling will occur in December 2012 and that the soil/rock core collection and well installation will occur in February/March 2013.

Table 8. Schedule of Deliverables

Deliverable	Internal Draft	Draft(1)	Final(1)
Implementation Plan and Project Schedule	August 2012	September 2012	November 2012
Work Plan – Area A and C Well Profiling(2)	September 2012	October 2012	November 2012
Technical Memorandum – Area A Well Profiling Evaluation(2)	March 2013	April 2013	May 2013
Technical Memorandum – Area C Well Profiling/Optimization Evaluation(2)	April 2013	May 2013	June 2013
Work Plan and UFP-SAP – Soil and Rock Core Collection(3)	March 2013	April 2013	May 2013
Technical Memorandum – Bench Scale Testing(3)	May 2013	June 2013	July 2013
Technical Memorandum – Pilot/Full Scale ISCO Source Treatment Design(3)	August 2013	October 2013	December 2013

(1) It is assumed that comments will be submitted 30 days after report submittal, and two weeks will be required to incorporate comments into the subsequent report version.
(2) Deliverable timeframe assumes associated field sampling activities will take place in December 2012.
(3) Deliverable timeframe assumes associated field sampling activities will take place in February/March 2013.

Section 6.0: REFERENCES

Battelle. 2011. *Remedial Action Evaluation Report for Operable Units 1A, 3, and 4 Groundwater Treatment System at NAWC Warminster, Pennsylvania.* July.

Foster-Wheeler Environmental Corporation. 1999. *Installation/Testing of Area A Groundwater Extraction Wells at NAWC Warminster, PA.* June.

Halliburton NUS, Corp. 1994. *Focused Feasibility Study Report for Operable Unit 3, Naval Air Warfare Center (NAWC), Warminster, PA*. August.

Halliburton NUS, Corp. 1993. *Phase II RI Report, Vol. 1 for OU-1 NAWC Warminster, PA.* April.

H&S Environmental, Inc. 2011. *Final Sampling and Analysis Plan (Field Sampling Plan and Quality Assurance Project Plan) for Long-Term Groundwater Monitoring at Operable Units 1A, 3, and 4, Former Naval Air Warfare Center, Warminster, Pennsylvania*. October.

Tetra Tech. 2009. *Hydrogeologic Conceptual Site Model Update*. December

Tetra Tech NUS, Inc. 2007. *Area C Source Assessment Report, Former Naval Air Warfare Center Warminster, Warminster, Pennsylvania.* December.

Tetra Tech NUS, Inc. 2000. *RI/FS For OU-9 for NAWC Warminster, PA, Vol. II (Appendices).* April.

United States Environmental Protection Agency. 2000. *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study.* Office of Solid Waste and Emergency Response. EPA 540-R-00-002. July.

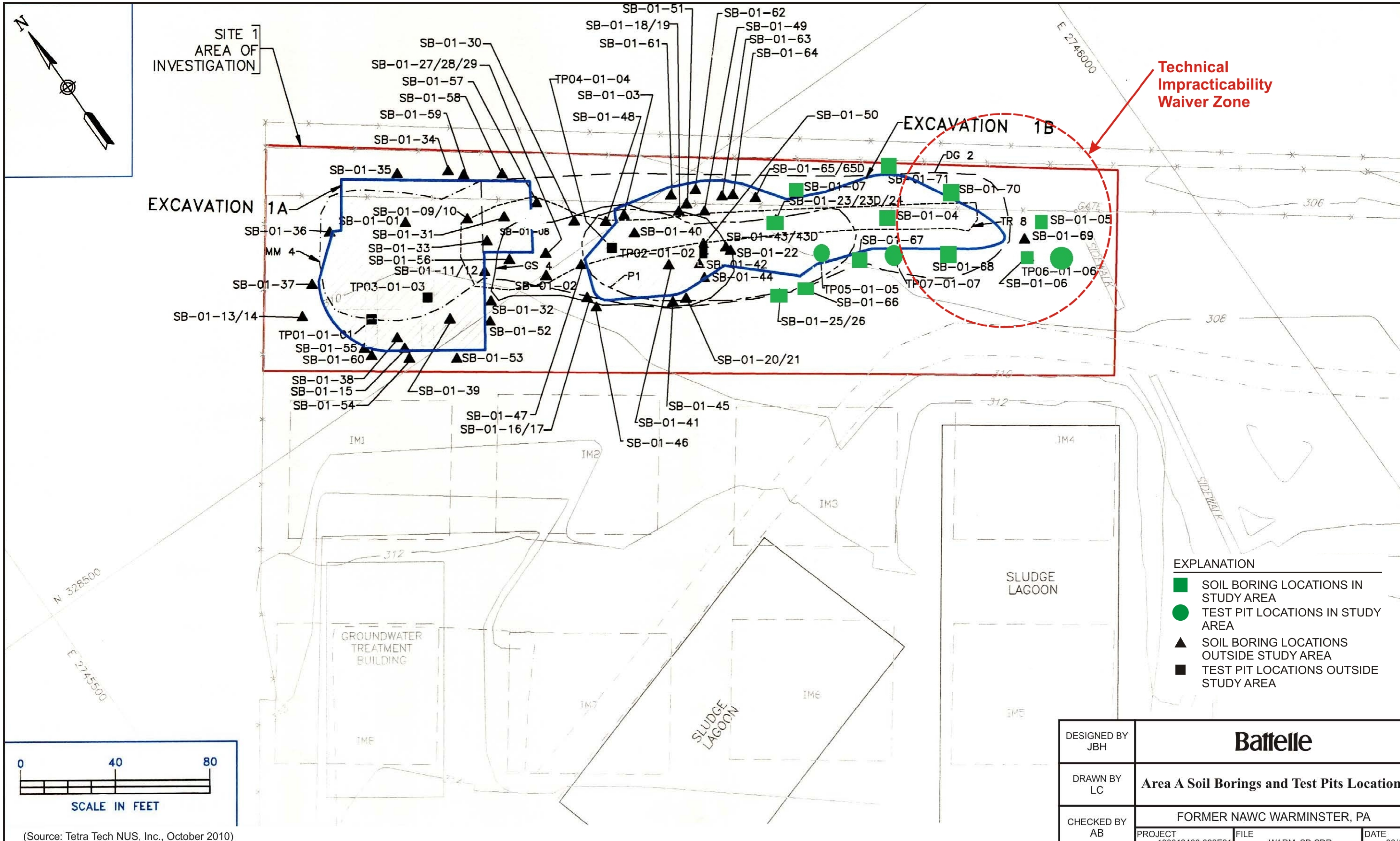
United States Geological Survey. 2008. *Interpretation of Borehole Geophysical Logs at Area C, Former Naval Air Warfare Center, Warminster Township, Bucks County, Pennsylvania, 2007.* Open-File Report 2008-1207.

U.S. EPA, see United States Environmental Protection Agency.

USGS, see United States Geological Survey.

ATTACHMENT 1

LOCATION OF HISTORICAL AREA A SOIL BORINGS AND TEST PITS


SITE 1 AREA OF INVESTIGATION
EXCAVATION 1A
EXCAVATION 1B
Technical Impracticability Waiver Zone
SB-01-51
SB-01-18/19
SB-01-61
SB-01-62
SB-01-49
SB-01-63
SB-01-64
SB-01-30
SB-01-27/28/29
SB-01-57
SB-01-58
SB-01-59
SB-01-34
SB-01-35
TP04-01-04
SB-01-03
SB-01-48
SB-01-50
SB-01-65/65D
SB-01-07
SB-01-23/23D/24
SB-01-71
SB-01-70
DG 2
SB-01-04
SB-01-05
TR 8
SB-01-69
SB-01-09/10
SB-01-01
SB-01-31
SB-01-33
SB-01-56
SB-01-11/12
SB-01-36
MM 4
SB-01-37
SB-01-13/14
TP03-01-03
TP01-01-01
SB-01-55
SB-01-60
SB-01-53
SB-01-38
SB-01-15
SB-01-54
SB-01-39
SB-01-32
SB-01-52
GS 4
SB-01-02
SB-01-40
TP02-01-02
P1
SB-01-43/43D
SB-01-22
SB-01-42
SB-01-44
SB-01-67
SB-01-68
TP05-01-05
SB-01-66
TP07-01-07
TP06-01-06
SB-01-06
SB-01-25/26
SB-01-20/21
SB-01-47
SB-01-16/17
SB-01-45
SB-01-41
SB-01-46
GATE
SIDEWALK
306
308
310
312
IM1
IM2
IM3
IM4
IM5
IM6
IM7
IM8
SLUDGE LAGOON
SLUDGE LAGOON
GROUNDWATER TREATMENT BUILDING
E 2746000
N 328500
E 2745500
N
0 40 80
SCALE IN FEET
(Source: Tetra Tech NUS, Inc., October 2010)
EXPLANATION
SOIL BORING LOCATIONS IN STUDY AREA
TEST PIT LOCATIONS IN STUDY AREA
SOIL BORING LOCATIONS OUTSIDE STUDY AREA
TEST PIT LOCATIONS OUTSIDE STUDY AREA
DESIGNED BY JBH
DRAWN BY LC
CHECKED BY AB
Battelle
Area A Soil Borings and Test Pits Locations
FORMER NAWC WARMINSTER, PA
PROJECT 100012466-022E21
FILE WARM_SB.CDR
DATE 08/12

ATTACHMENT 2

COMMENT RESPONSE FORM

Author	Section	Comment	Response
KD	3.2 4.1	It is proposed to use passive diffusion bag samplers in preferred sample locations based on hydraulically-active fractures in monitoring wells and extraction wells. It is recommended that intraborehole flow is considered in determining if depth discrete representative samples can be taken in a well screened/open over more than one fracture/fracture zone. It is recommended that results previously generated using the heat-pulse flowmeter are included in the analysis. If they do not exist, it is recommended that the flow tests are conducted.	Agree with comment. As part of the well profiling activities, the Navy is proposing that the USGS would collect new heat pulse flow meter (HPFM) logs and base passive diffusion bag placement decisions on the results. The text in Section 3.2 and 4.1 was updated to include a brief discussion of the approach. HPFM testing is detailed in Sections 2.2.3 and 3.2.3 of the "Draft Area A and C Well Profiling Work Plan for Source Treatment Optimization".
RS	Table 2	The fracture zones in the table may not be hydraulically active fracture zones. The information in the table should be supplemented with borehole geophysical data.	Agree with comment. Text in Section 2.1.1 was updated to indicate that the fracture zones presented in Table 2 may not be hydraulically active, and that the information should be confirmed during well profiling activities.
RS	3.2	The text indicates that only the unsaturated soil zone would be tested for residual contamination. It is possible that considerable contamination is present in the matrix of the bedrock. The upper (weathered) part of the bedrock may have a high porosity and may also hold residual contamination. Selection of samples from discrete rock cores should not be based on vertical profiling and drilling logs for existing wells. The selection of samples should be based on the cores themselves or geophysical logs run in the core holes.	Agree with comment. The soil/rock cores will be conducted continuously from land surface into the mudstone unit at the base of hydrogeologic unit B. Text in Section 3.2 was updated to state that testing will be performed on samples collected from the unsaturated zone soil, weathered bedrock, and bedrock.
JO	2.1.2	After the *initial* excavation was completed,… …no further human health risks ~~given~~ *for the* reasonably anticipated land uses	Agree with comment and text modified accordingly.
JO	2.2	Mention how the OUs were closed, i.e. OU-2 by providing public water, OU-6 by excavating the wastes.	Agree with comment. The text was updated by providing a description of how the OUs were closed.
JO	Figures 8 and 9	ID the hydrogeologic units on Figures 8/9.	The text in Section 2.2 provides a description of the distinction between the shallow and deep hydrogeologic unit. A review of historic OU-3 documentation did not reveal a precise delineation of the boundary between the two hydrogeologic units, so the figures were not updated.
JO	2.2.1	*In May 2012*, the maximum PCE …. Detections *of PCE in this well* ~~in an upgradient replacement monitoring well (HN23A)~~ have….. detections since June 2011 have been below 100 ug/l. ~~with the most recent detection in May 2012 being 65 ug/l~~.	
JO	2.2.2	…have been performed to *attempt to* identify the ~~potential~~ source for…	Agree with comment and text modified accordingly.
JO	2.2.2	Provide a reference for the groundwater modeling that is referred to.	Agree with comment and text was updated with a reference.
JO	4.2	Identify the Decision – Should be “within Area C”, not A.	Agree with comment and text modified accordingly.